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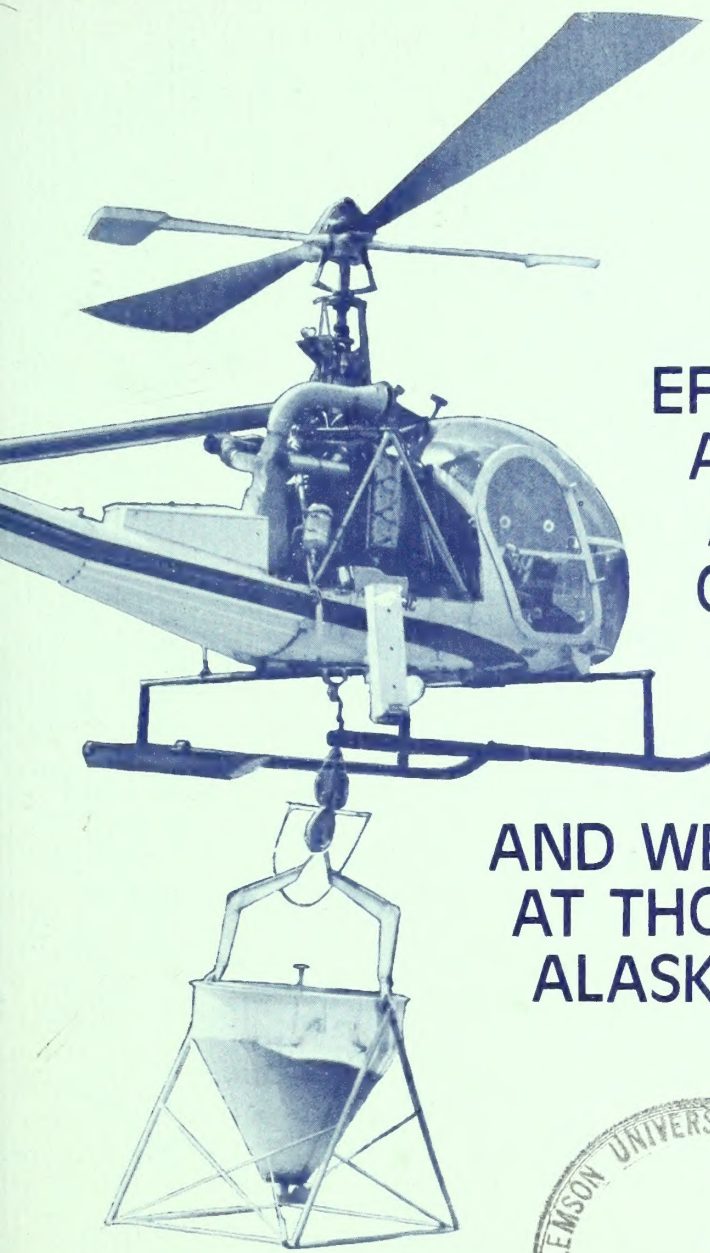

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# EFFECTS OF AN AERIAL APPLICATION OF UREA FERTILIZER ON YOUNG SITKA SPRUCE AND WESTERN HEMLOCK AT THOMAS BAY, ALASKA

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# *Effects of an Aerial Application of Urea Fertilizer on Young Sitka Spruce and Western Hemlock at Thomas Bay, Alaska.*

*Reference Abstract*

Farr, Wilbur A., A. S. Harris, and Spencer N. Israelson
1977. Effects of an aerial application of urea fertilizer on young Sitka spruce and western hemlock at Thomas Bay, Alaska. USDA Forest Serv. Res. Pap. PNW-219, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

In May 1969, about 1,500 acres (607 ha) of 6- to 10-year-old western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) were fertilized with agricultural grade urea at the rate of 400 pounds of urea per acre (448 kg/ha). No response in growth was detected the 1st year, but concentrations of nitrogen in the foliage about doubled. By 1971, nearly all hemlock on the fertilized and unfertilized areas was suffering from tip and leader dieback caused by the fungus *Sirococcus strobilinus*. Because of the fungus, hemlock growth could not be evaluated. Height and diameter growth of spruce increased 20 to 30 percent the second growing season. By the 5th or 6th year, there was little difference in growth, the net effect being that fertilized spruce were then about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than similar unfertilized trees.

KEYWORDS: Nitrogen fertilizer response, fertilizer (-natural regeneration, regeneration (natural), fertilizer application methods, spraying (aerial), increment (height), increment (diameter), Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, fungi (-forest damage, *Sirococcus strobilinus*.

## *RESEARCH SUMMARY*

*Research Paper PNW—219*

*1977*

Encouraging results from small-plot trials treated with nitrogen fertilizer led to pilot projects from which experience was gained in costs, logistics in remote areas, and methods of applying fertilizer. One project took place on a glacial outwash plain at Thomas Bay, Alaska, where the effects of fertilization on tree growth were also assessed. Hemlock and spruce averaged 4 to 7 feet (1.2 to 2.1 m) in height, and all areas were stocked with 3,000 to 6,000 stems per acre (7 413 to 14 826/ha). Soils, which developed following glacial retreat, were relatively youthful and essentially well drained.

In May 1969, 310 tons (281 metric tons) of agricultural grade urea fertilizer was aerially applied by helicopter to four cutover units totaling about 1,500 acres (607 ha). The reported cost was $38.70 per acre ($95.63/ha). Height growth was measured annually through 1974. Foliage samples were also collected and analyzed in 1969, 1972, 1973, and 1974; and an analysis was made of annual diameter growth for the years 1966 through 1973.

There was no diameter or height response the first growing season although the concentration of nitrogen in the foliage of fertilized hemlock

and spruce was about twice that in unfertilized trees. By the third growing season after fertilization, most hemlock was infected with the fungus *Sirococcus strobilinus*. Both fertilized and unfertilized hemlock were equally affected. No analysis was made of the growth of hemlock because repeated tip and leader dieback greatly affected hemlock development. Spruce was not affected by dieback.

Height and diameter growth of spruce increased 20 to 30 percent the second growing season but declined thereafter. By 1973 or 1974, there was little difference in growth between fertilized and unfertilized trees of similar size. At the end of the study, the fertilized trees measured about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than they would have been had they not been fertilized. Although there were immediate results in terms of stand appearance and growth response, the fertilizer did not produce long-lasting results.

For now, we would not encourage additional large-scale applications of fertilizer. Instead, more basic information is needed on the nutrient requirements of hemlock and spruce and the effect of soils on fertilizer response. Information is not available on the results of fertilizing young stands growing on better developed upland soils.

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# Introduction

During the 1960's, a growing interest in forest fertilization developed throughout the world. This interest was prompted by diminishing supplies of timber and increasing demand for wood. Research focused on problems of tree nutrition and opportunities for improving yields through fertilization. A compilation of world literature from 1957 through 1964 included 1,215 publications pertaining to forest fertilization research (Mustanoja and Leaf 1965).

In the Pacific Northwest, interest in forest fertilization can be traced back to about 1950 when fertilizer trials were begun in immature Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands in western Washington (Gessel et al. 1969). Results were encouraging enough that by the mid-1960's private timber companies in the Pacific Northwest and Canada were aerially applying nitrogen (N) in the form of urea over many thousands of acres (Clark 1967, Forbes 1966).

Although most attention in the Pacific Northwest has been on Douglas-fir, considerable interest has also been shown in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). By 1975, fertilizer trials had been established on about 1,000 hemlock plots (DeBell 1975, DeBell et al. 1975).

In the case of Sitka spruce (*Picea sitchensis* (Bong.) Carr.), little experience has been gained in the United States although a great deal of work has been done in Great Britain. Extensive studies on the nutrition of Sitka spruce, mainly in nurseries, date back to the 1950's (Benzian 1965). By the mid-1960's, large areas of immature stands of Sitka spruce had been aerially fertilized in Scotland (Davies 1967, 1969).

Most emphasis on fertilization research has been on growth and yield of stands, but the environmental effects of large-scale fertilization have also received attention. A state-of-the art review with a description of environmental effects of fertilization was prepared in 1972: 52 studies were cited (Groman 1972).

Interest in forest fertilization in southeast Alaska developed in the 1960's. Forest soils were found to be deficient in available nitrogen, and small plot trials showed that added nitrogen significantly increased the growth of western hemlock and Sitka spruce (Johnson 1970).

Encouraging results from these trials prompted the U.S. Forest Service to test large-scale aerial applications of urea in young stands of hemlock-spruce. The projects summarized below were undertaken mostly to gain experience in methods, costs, and logistics of large-scale applications in remote areas, (Johnson 1970, Bowkett 1969):

| Year | Location | Area in acres (hectares) | Age of regeneration in years |
|---|---|---|---|
| 1969 | Thomas Bay | 1,500 (591) | 6-10 |
| 1970 | Mitkof Island | 1,500 (591) | 5-10 |
| 1971 | Prince of Wales Island | 1,500 (591) | 6-10 |
| 1972 | Kosciusko Island | 930 (366) | 15 |

Scattered cuttings at each location were fertilized by helicopter with urea prills (46-percent nitrogen by weight) at a rate of 400 pounds per acre (448 kg/ha).

In addition to experience gained on application costs and problems, effects of fertilization have been studied at two of the four sites. At Falls Creek on Mitkof Island, Meehan et al. (1975) found an initial short-term increase in ammonia-nitrogen in one stream, apparently from the direct application of fertilizer. The concentration never exceeded 1.28 mg/liter, a concentration well below that considered toxic to aquatic life. Concentrations of nitrate nitrogen in both streams remained higher than normal during a 1-year sampling period but never exceeded 2.36 mg per liter, far below the upper limits for human consumption defined as 10 mg per liter if reported as N and 45 mg per liter if reported as $NO_3^-$.

Foliar analysis of western hemlock and Sitka spruce and height and diameter growth of individual spruce trees were studied at Thomas Bay and are reported here. Western hemlock was severely diseased by the fungus *Sirococcus strobilinus* so a meaningful analysis of its growth was not possible.

## Fertilizer Application

In May 1969, 310 tons (281 metric tons) of agricultural grade urea fertilizer was aerially applied by helicopter to four cutover units (totaling about 1,500 acres or 607 ha) at Thomas Bay (fig. 1).

Spreader-hoppers were used to distribute urea (fig. 2). Average flying distance from helispots to the project area was about 1 mile (1.6 km).

Agricultural grade urea prill was used because larger size forestry grade was not obtainable. This limited the effective swath width to 30-40 feet (9-12 m) and increased the cost of application.[1/]

Fertilizer traps, 4 square feet (0.37 $m^2$) in area, placed throughout the fertilized units, indicated that the fertilizer was well distributed although no analysis was made of the distribution. Costs for the project averaged $38.70 per acre ($95.63/ha) (see footnote 1).

1/ Information on file at Forestry Sciences Laboratory, Juneau, Alaska.

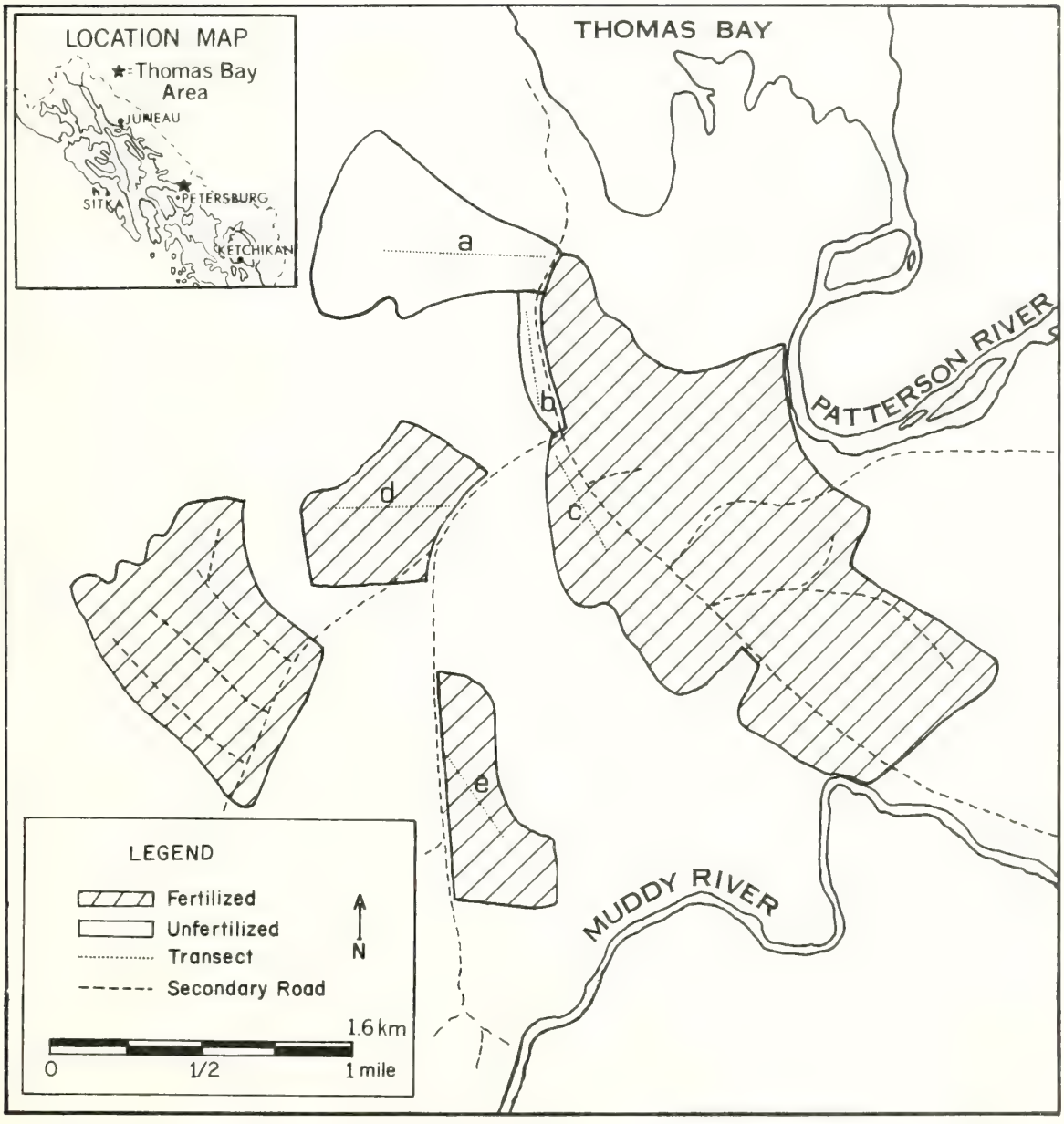


*Figure 1.--Fertilized and unfertilized stands and location of sample transects at Thomas Bay, Alaska.*

*Figure 2.--Loading urea fertilizer in spreader-hopper for aerial application by helicopter, Thomas Bay, Alaska.*

The fertilized units were located on a glacial-outwash plain in front of Patterson Glacier. Soils are relatively youthful, having developed after glacial retreat. The soils are generally excessively well-drained, coarse sands and coarse sandy loams. They do not exhibit thixotropic properties common to most mature soils in southeast Alaska because of their low levels of incorporated iron and humus. The area is somewhat unusual in that outwash plains this large are not as common as other soil types in southeast Alaska. Therefore, results of this study apply only to similar conditions. Before logging, cutover units supported mature mixed stands of western hemlock and Sitka spruce averaging 46,000 board feet per acre ($\sim$647 $m^3$ per hectare).

## Methods

In the fall of 1969, sample trees were selected in fertilized and unfertilized units so growth response to fertilization could be measured. Spruce and hemlock regeneration averaged 5 to 8 feet (1.5-2.4 m) in height, and all areas were stocked with 3,000 to 6,000 trees per acre (7,413 to 14,826/ha). Because trees were small and crown closure was not complete (fig. 3), volume response on an area basis could not be measured. Instead, height and diameter growth of individual trees were measured.

*Figure 3.--At the time of fertilization, the stand averaged 4 to 7 feet in height, with 3,000 to 6,000 stems per acre.*

A 20-chain transect was run through each of three fertilized units and through two unfertilized units (fig. 1). At 66-foot (20-m) intervals along each transect, the nearest dominant spruce and hemlock were selected as permanent sample trees--20 trees of each species. Total height, current year's growth, and annual height growth for the 3 years before fertilization were recorded. At the same time, a sample of the current year's foliage was clipped from the upper third of the crown of each tree.

Air drying of the foliage began immediately after collection. Within 3 to 5 days, all samples were ovendried at 149-158 °F (65-70 °C) for 24 hours. Foliage was removed from twigs, and ground in a Wiley[2/] mill to pass a 40-mesh screen, and bagged in transparent plastic envelopes for later analysis.[3/]

We noticed that color differences were apparent in the foliage samples, so two independent observers compared the dried ground samples with standard Munsell color chips (Munsell 1963) in a laboratory well illuminated by fluorescent lights. The Munsell color chips were viewed through plastic similar to that enclosing the samples. Results from the two observers were then compared and any differences resolved by a third observer. Additional foliar samples were taken after the fourth, fifth, and sixth growing seasons.

Annual height growth of all hemlock and spruce sample trees was measured each fall from 1969 through 1974.

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[2/] Mention of products by name does not constitute an endorsement by the U.S. Department of Agriculture to the exclusion of other products which may be suitable.

[3/] Foliar nutrient concentrations were determined after the first and fourth growing seasons by the Department of Soils, University of Alaska, after the fifth season by the Department of Forest Soils, Washington State University, and after the sixth season by the University of Washington.

In the fall of 1973, five growing seasons after fertilization, sample trees were felled and sectioned so diameter development could be measured. A dominant spruce of comparable height and diameter was selected within 33 feet (10 m) of each sample spruce tree; these trees were felled instead of the trees used to measure annual height growth. These were felled and sectioned at 2 and 4.5 feet (0.6 and 1.4 m) above ground. Moist cross sections were stored in plastic bags at a cool temperature, and annual radial growth was determined in the laboratory from averages of measurements across each of four diagonals for the years 1966 through 1973.

Statistical analysis of the test results was complicated by too few replications (three areas of fertilized and two of control), plus the fact that the observations were not independent (i.e., the same trees were remeasured several years). Also, because of the variation in tree size, mean growth of trees in fertilized and unfertilized areas could not be directly compared. Therefore, we used analysis of covariance fitting a linear relationship between height growth and total height for each area. Height growth between fertilized and unfertilized trees was compared by testing for differences between selected curves. A similar analysis was used for diameter growth with diameter as a covariate. From this, we drew general conclusions, being careful not to place emphasis on any single test as conditional testing affects the probability involved in each test. The reader should keep these statistical limitations in mind when interpreting results.

When the initial measurements were made in the fall of 1969, both hemlock and spruce were tagged for future remeasurement and all appeared healthy. By the fall of 1970, however, many hemlock appeared to be suffering from a tip and leader dieback. This cause was later identified as the fungus *Sirococcus strobilinus*. This fungus, reported on young hemlock in Canada (Funk 1972), occurs at several locations in southeast Alaska.

By fall 1971, nearly all hemlock on both fertilized and unfertilized units appeared to be affected by the fungus; it was apparent that the growth response of western hemlock could not be evaluated. The fungus was not detected on any of the spruce sample trees. Therefore, analysis of growth has been confined to the spruce component of the stand. Fertilization does not appear to have increased susceptibility of hemlock to attack by this fungus as both treated and untreated areas were equally affected.

## Results

### *HEIGHT GROWTH*

Height growth of fertilized Sitka spruce increased 20 to 25 percent during the second growing season after fertilization; no difference was detected the 1st year.

Before fertilization, mean tree height ranged from 4 to 7 feet (1.2 to 2.1 m) on the five areas and ages ranged from 5 to 11 years (table 1); this complicated the analysis.

Before fertilization there were no significant differences in height growth between areas for trees of similar height (table 2). The same was true for 1969, the first growing season after fertilization. In the second growing season (1970), height growth of fertilized trees was significantly greater for the range of heights sampled.

Table 1.--*Mean total height of Sitka spruce at Thomas Bay, Alaska, by area and year*

| Area | Age at end of 1968 | Before fertilization | | | After fertilization | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1966 | 1967 | 1968 | 1969[1/] | 1970 | 1971 | 1972 | 1973 | 1974 |
| | Years | - - - - - - - - - - - - - - - - - - Feet - - - - - - - - - - - - - - - - - - | | | | | | | | |
| Unfertilized: | | | | | | | | | | |
| A | 5 | 1.88 | 2.58 | 3.57 | 4.55 | 5.51 | 6.49 | 7.59 | 8.67 | 9.71 |
| B | 11 | 2.70 | 3.55 | 4.62 | 5.77 | 6.82 | 8.01 | 9.32 | 10.64 | 11.86 |
| Mean | 8 | 2.29 | 3.07 | 4.10 | 5.16 | 6.17 | 7.25 | 8.46 | 9.66 | 10.79 |
| Fertilized: | | | | | | | | | | |
| C | 9 | 2.95 | 3.93 | 5.09 | 6.22 | 7.67 | 9.16 | 10.69 | 12.28 | 13.67 |
| D | 6 | 4.34 | 5.38 | 6.83 | 8.08 | 9.87 | 11.58 | 13.45 | 15.36 | 17.04 |
| E | 6 | 2.77 | 3.63 | 4.79 | 6.11 | 7.57 | 9.14 | 10.98 | 12.76 | 14.17 |
| Mean | 7 | 3.35 | 4.31 | 5.57 | 6.80 | 8.37 | 9.96 | 11.71 | 13.47 | 14.96 |

[1/] Fertilizer was applied in May.

Table 2.--*Analysis of covariance "F" values[1/] for tests of differences in height growth before and after fertilization at Thomas Bay, Alaska*

| Area comparisons[2/] | Before fertilization | | After fertilization | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
| A versus B | 0.02 | 0.92 | 0.31 | 0.70 | 0.04 | 0.04 | 3.91 | 0.04 |
| A versus C | .82 | 0 | 0 | 4.54* | 2.98 | .38 | 2.50 | 1.22 |
| A versus D | 1.53 | .03 | 1.21 | 8.22** | 3.95 | 1.06 | 1.28 | 1.46 |
| A versus E | .05 | 0 | 3.13 | 10.70** | 5.48 | 6.35* | 4.94* | .50 |
| B versus C | .07 | .09 | .01 | 4.50* | 2.44 | .31 | .58 | .99 |
| B versus D | 2.28 | .32 | .71 | 8.20** | 4.25* | 5.93* | 3.40 | .04 |
| A + B versus C+D+E | 1.73 | .11 | 1.22 | 17.80** | 9.23** | 4.42* | 4.21* | .70 |

[1/] In the analysis of covariance two null hypotheses were tested: (1) that the simple regression lines were parallel and (2) that the adjusted means were equal, where Y=height growth in year i and X=total height at the end of year i-1.

Hypothesis 1 was accepted in all cases, and "F" values are not shown; "F" values for hypothesis 2 are given.

[2/] Areas C, D, and E were fertilized; areas A and B were not fertilized.

* Significant at the 5-percent level of probability.

** Significant at the 1-percent level of probability.

In the years following 1970, the benefits of urea fertilization appeared to lessen; by 1974 there were no significant differences in height growth of fertilized and unfertilized trees.

## *DIAMETER GROWTH*

At the time of fertilization, many sample trees had not yet reached breast height. Therefore, diameter growth was compared at a height of 2 feet (0.6 m) above the root collar (table 3).

Before fertilization, the relationship between diameter growth and diameter was similar for all areas (table 4). With one exception, the same was true in 1969, the first growing season after fertilization. In 1970 and 1971, the fertilized trees showed for most comparisons a highly significant response to fertilization. On a percentage basis the response was about 25 to 30 percent. Response appeared to decline after 1971, and by 1973 there were indications that differences in growth rates were once again at or near the level of nonsignificance.

*Table 3.--Mean diameter 2 feet above the root collar of Sitka spruce at Thomas Bay, Alaska, by area and year*

| | Before fertilization | | | | After fertilization | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Area | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 |
| | | | | | Inches | | | | |
| Unfertilized | | | | | | | | | |
| A | 0.13 | 0.26 | 0.45 | 0.68 | 0.92 | 1.20 | 1.50 | 1.79 | 2.10 |
| B | .26 | .39 | .55 | .73 | .94 | 1.18 | 1.45 | 1.73 | 2.05 |
| Mean | .20 | .33 | .51 | .71 | .93 | 1.19 | 1.47 | 1.76 | 2.07 |
| Fertilized | | | | | | | | | |
| C | .23 | .38 | .55 | .75 | .96 | 1.28 | 1.63 | 1.99 | 2.39 |
| D | .39 | .56 | .76 | .99 | 1.29 | 1.68 | 2.10 | 2.46 | 2.86 |
| E | .13 | .23 | .40 | .59 | .83 | 1.17 | 1.54 | 1.90 | 2.28 |
| Mean | .25 | .39 | .57 | .78 | 1.02 | 1.38 | 1.76 | 2.11 | 2.51 |

*Table 4.--Analysis of covariance "F" values[1/] for tests of differences in diameter growth before and after fertilization at Thomas Bay, Alaska*

| Area [2/] | Before fertilization | | | | | | After fertilization | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1966 | | 1967 | | 1968 | | 1969 | | 1970 | | 1971 | | 1972 | | 1973 | |
| | Slopes | Adjusted means | Slopes | Adjusted means | Slopes | Adjusted means | Slopes | Adjusted means | Slopes | Adjusted means | Slopes | Adjusted means | Slopes | Adjusted means | Slopes | Adjusted means |
| A versus B | 3.19 | 0.40 | 1.18 | 1.[illegible] | 0.12 | 5.63* | 0.42 | 1.70 | 0.24 | 1.63 | [illegible] | 0.71 | 0 | 0.14 | 0 | 0.12 |
| [illegible] | 1.75 | [illegible] | .26 | .60 | 06 | 1.17 | .13 | 2.53 | .43 | 1.53 | .12 | 1.46 | .22 | 2.53 | .30 | 4.64* |
| [illegible] | .74 | 1.45 | .38 | .11 | .11 | .08 | [illegible] | 2.13 | 0 | 3.97 | [illegible] | 2.01 | .31 | .63 | .44 | .63 |
| [illegible] | 2.07 | .93 | 2.17 | [illegible] | .4[illegible] | .99 | [illegible] | [illegible] | 5.58* | 5.94* | 3.80 | 3.06 | 3.42 | 3.20 | 2.29 | 3.92 |
| B versus C | .37 | 2.34 | .38 | [illegible] | .7 | 1.67 | .19 | .04 | .74 | 9.19*** | .48 | 10.1*** | .34 | 5.05* | .42 | 4.01 |
| [illegible] | 2.02 | 3.79 | .46 | 88 | 1 00 | 3.69 | [illegible] | 10.70*** | .34 | 16.6*** | 1.33 | 10.9** | .53 | 1.87 | .65 | .28 |
| [illegible] | .21 | [illegible] | 1.09 | 26 | 39 | 1.20 | 3.23 | 3.33 | 15.60*** | 16.10*** | 9.85*** | 12.30*** | 5.74* | 5.66* | 3.28 | 2.50 |
| A+B versus [illegible] | .35 | .39 | .32 | [illegible] | .01 | .12 | .51 | 1.48 | 1.14 | 16.2*** | [illegible] | 12.1*** | .71 | 6.46* | .64 | 5.12* |

1/ In the analysis of covariance two hypotheses were tested: (1) that the slopes of the simple regression lines were equal and (2) that the adjusted means were equal, where [illegible] growth in year [illegible] and [illegible] diameter at the end of year [illegible].

2/ Areas C, D, and E were fertilized; areas A and B were not fertilized.

* Significant at the 5-percent level of probability.
** Significant at the 1-percent level of probability.
*** Significant at the 0.5-percent level of probability.

## FOLIAR NUTRIENT CONCENTRATIONS

Foliage collected from each sample tree in 1969 was analyzed separately, and means and standard errors were computed for each nutrient by area. In 1972, 1973, and 1974, foliage from the sample trees was mixed as a composite sample so estimates of variation are not available.

After the first growing season following fertilization (1969), there were significant differences between percent nitrogen in fertilized and unfertilized hemlock and spruce (tables 5 and 6). After four growing seasons (1972), concentrations of N in spruce were about the same. In hemlock, the concentrations of N, though not significant, were generally higher in fertilized trees until 1974 when the levels were slightly higher in unfertilized trees.

Table 5--*Mean nutrient concentrations in the foliage of Sitka spruce at Thomas Bay, Alaska*[1/]

| Area and year | Dry matter concentrations | | | | | | |
|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Zn |
| | Percent | | | | | Parts per million | |
| Unfertilized: | | | | | | | |
| A--1969 | 1.18a | 0.16a | 0.45a | 0.26a | 0.065ab | 465a | 29a |
| 1972 | .99 | .17 | .54 | .31 | .096 | -- | -- |
| 1973 | .90 | -- | -- | -- | -- | -- | -- |
| 1974 | .94 | -- | -- | -- | -- | -- | -- |
| B--1969 | 1.26a | .16a | .46a | .31a | .063ab | 424a | 26a |
| 1972 | 1.06 | .19 | .62 | .37 | .092 | -- | -- |
| 1973 | .86 | -- | -- | -- | -- | -- | -- |
| 1974 | 1.07 | -- | -- | -- | -- | -- | -- |
| Fertilized: | | | | | | | |
| C--1969 | 2.57b | .18a | .44a | .29a | .053b | 442a | 17b |
| 1972 | .99 | .16 | .60 | .28 | .084 | -- | -- |
| 1973 | 1.06 | -- | -- | -- | -- | -- | -- |
| 1974 | 1.06 | -- | -- | -- | -- | -- | -- |
| D--1969 | 2.25b | .18ab | .44a | .28a | .056ab | 408a | 26a |
| 1972 | .99 | .17 | .51 | .29 | .081 | -- | -- |
| 1973 | .95 | -- | -- | -- | -- | -- | -- |
| 1974 | 1.05 | -- | -- | -- | -- | -- | -- |
| E--1969 | 2.47b | .21b | .50a | .30a | .066a | 428a | 27a |
| 1972 | 1.14 | .18 | .64 | .34 | .084 | -- | -- |
| 1973 | .97 | -- | -- | -- | -- | -- | -- |
| 1974 | .99 | -- | -- | -- | -- | -- | -- |

[1/] Values are averages for 20 samples obtained from 20 trees. Values for 1969 in each column followed by the same letter are not significantly different (Tukey test, $P<0.05$). -- = no data.

Table 6--*Mean nutrient concentrations in the foliage of western hemlock at Thomas Bay, Alaska*[1/]

| Area and year | Dry matter concentrations | | | | | | |
|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Zn |
| | Percent | | | | | Parts per million | |
| Unfertilized: | | | | | | | |
| A--1969 | 1.31a | 0.23a | 0.49a | 0.21ab | 0.088a | 558a | 21a |
| 1972 | .98 | .23 | .64 | .26 | .146 | -- | -- |
| 1973 | .98 | -- | -- | -- | -- | -- | -- |
| 1974 | 1.00 | -- | -- | -- | -- | -- | -- |
| B--1969 | 1.34a | .20a | .57ab | .24b | .088a | 600a | 14b |
| 1972 | .91 | .23 | .72 | .28 | .144 | -- | -- |
| 1973 | 1.08 | -- | -- | -- | -- | -- | -- |
| 1974 | 1.13 | -- | -- | -- | -- | -- | -- |
| Fertilized: | | | | | | | |
| C--1969 | 2.12b | .21a | .58b | .19ac | .074ab | 530a | 23a |
| 1972 | 1.31 | .25 | .69 | .22 | .124 | -- | -- |
| 1973 | 1.16 | -- | -- | -- | -- | -- | -- |
| 1974 | 1.02 | -- | -- | -- | -- | -- | -- |
| D--1969 | 2.24b | .24a | .52ab | .17c | .070b | 524a | 26a |
| 1972 | 1.21 | .23 | .58 | .25 | .128 | -- | -- |
| 1973 | 1.28 | -- | -- | -- | -- | -- | -- |
| 1974 | .87 | -- | -- | -- | -- | -- | -- |
| E--1969 | 2.19b | .23a | .59b | .21abc | .078ab | 581a | 21ab |
| 1972 | 1.06 | .19 | .64 | .28 | .130 | -- | -- |
| 1973 | 1.20 | -- | -- | -- | -- | -- | -- |
| 1974 | .96 | -- | -- | -- | -- | -- | -- |

[1/] Values are averages for 20 samples obtained from 20 trees. Values in 1969 in each column followed by the same letter are not significantly different (Tukey test, $P<0.05$). -- = no data.

For unfertilized trees, mean concentrations of N were higher on all areas in 1969 than in later years and concentrations varied from year to year. These variations may be the result of year-to-year response of trees to climate. After discounting these variations, we still noted that N in fertilized trees was twice that in unfertilized trees at the end of the first growing season after fertilization.

At the same time, concentrations of P, K, Ca, Mg, and Mn in fertilized trees were about the same as in unfertilized trees. Some means were significantly different, but definite trends were not apparent.

## *FOLIAR COLOR*

The color of dried ground foliage of both hemlock and spruce differed between fertilized and unfertilized trees the first growing season after fertilization (fig. 4). Foliage of fertilized hemlock and spruce had a more greenish hue than did unfertilized samples; value was about the same but perhaps more variable in fertilized samples, and chroma tended to be lower (less intense) in fertilized than in unfertilized samples; in other words, greener, about as dark, and less intense. Color differences were not apparent in later years and comparisons made from Munsell charts were not recorded after the first growing season.

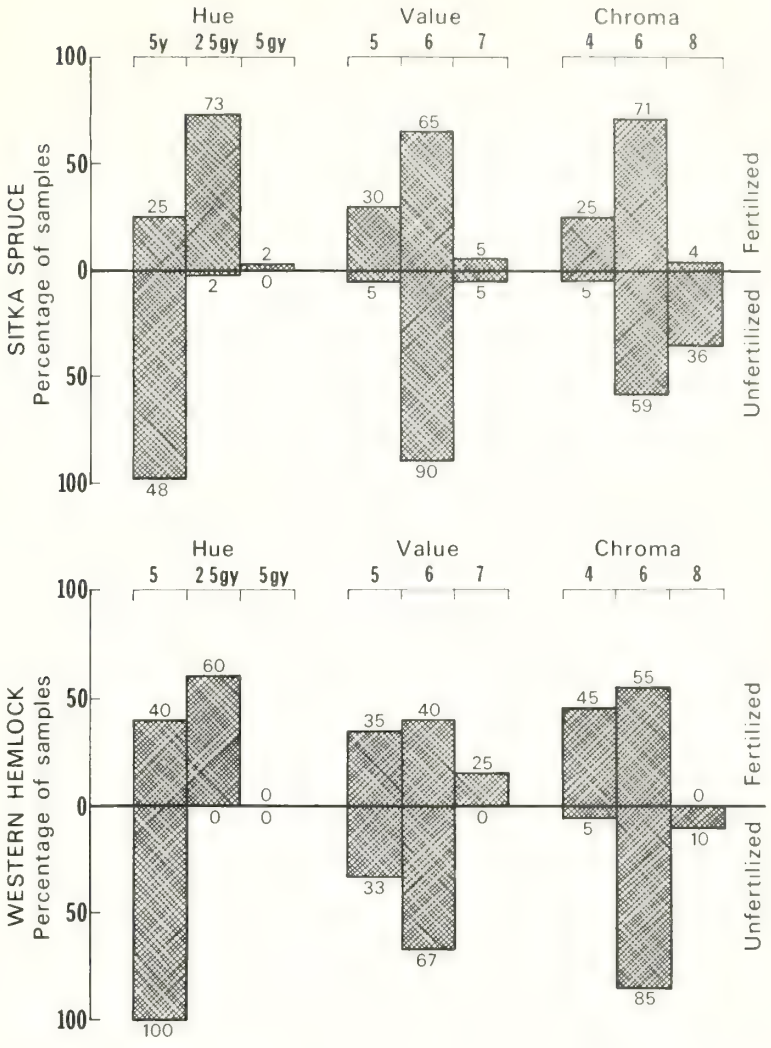


*Figure 4.--Percentage of dried foliage samples by color (hue, value, chroma) on fertilized and unfertilized plots, Thomas Bay, Alaska, 1969 ("g" refers to green and "y" refers to yellow).*

## Discussion

Fertilizer was applied at Thomas Bay in May 1969 to stimulate growth of Sitka spruce and western hemlock by providing an increase in nitrogen, considered to be in short supply.

By fall 1971, it became apparent that the hemlock was heavily infected with the fungus *Sirococcus strobilinus* (Funk 1972) and that the response of hemlock to fertilization could not be evaluated. Prevalence of the disease was not associated with fertilization as both fertilized and unfertilized areas were equally infected.

At present the relationship between fertilization and incidence of disease is not well known. Apparently reactions differ, and no general statements can be made. Much additional experience and study will be necessary before the adverse or beneficial effects of fertilization on disease control can be determined (Hesterberg and Jurgensen 1972).

Application of 400 pounds per acre (448 kg/ha) of urea fertilizer resulted in increased height and diameter growth of Sitka spruce beginning in 1970, the second growing season after fertilization. The greatest

increase took place in 1970; thereafter, the response lessened and by 1973 or 1974, there was little difference in growth between fertilized and unfertilized trees of similar size. Average height growth was increased 20 to 25 percent and diameter growth 25 to 30 percent with decreased height growth in later years. In all, the beneficial effects of urea fertilization appeared to last about 4 years, at which time, fertilized trees were about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than they would have been had they not been fertilized.

Response in terms of increased wood volume could not be evaluated because trees were small and only the growth of Sitka spruce was measured. Growth rates were increased for about 4 years. For this increase to be maintained, fertilization would have to be repeated at 4- to 5-year intervals.

Little is known about growth response of western hemlock to fertilization. Tests in the Pacific Northwest have produced mixed results. Best results have been obtained in the Washington Cascades, coastal Washington, and on Vancouver Island (DeBell 1975). The reasons for increased growth of hemlock are also not well understood, although an increase in leaf area and crown size with resulting efficiency in photosynthetic activity is thought to be important (DeBell 1975).

At Thomas Bay, concentrations of N and K were low in unfertilized trees (tables 5 and 6). Of major nutrients, K appeared to be in very short supply when compared with concentrations normally found in hemlock and spruce growing elsewhere on good sites (table 7).

Table 7--*Means and ranges (in parentheses) of nutrient concentrations of Sitka spruce and western hemlock in England and in the Maybeso Experimental Forest, Hollis, Alaska*

| Species | Ovendry weight | | | | | Source |
|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | |
| | - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - | | | | | |
| Sitka spruce: | | | | | | |
| Good growth | 1.59 (1.19-1.93) | 0.22 (0.19-0.34) | 1.27 (0.81-1.67) | 0.35 (0.25-0.55) | 0.14 (0.07-0.20) | Binns et al. 1970 |
| | 1.47 (1.07-1.76) | 0.24 (.18- .33) | 1.15 (.68-1.58) | .24 (.15- .40) | .12 (.09- .16) | Binns and Atterson 1967 |
| | 1.38 (1.05-1.66) | .22 (.13- .32) | .80 (.55-1.35) | .31 (.13- .56) | .09 (.06- .15) | 1/ |
| Poor growth | 1.09 (.86-1.34) | .16 (.09- .27) | .88 (.52-1.15) | .43 (.36- .59) | .14 (.08- .25) | Binns et al. 1970 |
| | .95 (.72-1.27) | .16 (.08- .19) | .69 (.30- .89) | .28 (.21- .37) | .10 (.08- .12) | Binns and Atterson 1967 |
| | .88 (.69-1.12) | .15 (.10- .21) | .65 (.42- .92) | .31 (.14- .50) | .07 (.03- .10) | 1/ |
| Western hemlock: | | | | | | |
| Good growth | 1.28 (1.00-1.48) | .28 (.18- .34) | .68 (.26- .94) | .20 (.09- .34) | .13 (.09- .17) | 1/ |
| Poor growth | .83 (.60-1.02) | .18 (.09- .40) | .62 (.40- .82) | .17 (.08- .28) | .09 (.07- .14) | 1/ |

1/ Data from the Maybeso Experimental Forest, Hollis, Alaska; on file at the Forestry Sciences Laboratory, Juneau, Alaska.

Concentration of nitrogen in foliage of fertilized trees was significantly higher than in unfertilized trees the first season after treatment but declined to lower levels within 3 years. Levels of other nutrients probably were not significantly affected by fertilization.

Our limited information relating nutrient concentration to growth in southeast Alaska makes it difficult to interpret the practical significance of nutrient values. Assessment of nutrient requirements for plants is imprecise. It is generally conceded that there is no single optimum level of concentration for each nutrient. Greenhouse experiments with Sitka spruce have shown that tree age and provenance affect nutrient concentrations in tissues of trees grown under the same supply of nutrients, and that the supply level of one nutrient may affect tissue concentration of several nutrients (van den Driessche 1969).

Sites at Thomas Bay have been deglaciated for only about 1,000 years, and soils are relatively youthful. Textures are stony, gravelly loamy sands with 50 to 90 percent coarse fragments estimated by volume. Soils are well drained. Organic matter is important as a medium of nutrient transfer from soils to plants as there is little clay or other colloidal material in the coarse mineral soil. The surface organic layer is shallow and where missing as a result of logging, tree growth is slow. Root systems and soil profile development are confined to the uppermost few inches of soil. We suspect that much of the nitrogen supplied by urea was leached out of the ecosystem within the first growing season or tied up in the surface organic layer. Lacking detailed chemical soil information, we can only speculate concerning the fate of applied urea.

## Conclusions

Aerial fertilization is an attractive tool in forest management because large areas may be treated quickly at minimum effort, almost immediate results may be obtained in terms of appearance of a stand, and an early increase in growth may occur. Fertilization, however, may not produce an economical or lasting increase in growth on glacial outwash soils such as those at Thomas Bay. Information for other soil types is not available.

In areas where timber values are high, where stands are close to the mill, and where rotations are short, fertilization may be useful, especially when combined with thinning or other intensive cultural measures.

More basic information is needed on nutrient requirements of hemlock and spruce in Alaska and on the effects of soils on fertilizer response. Further investigation of environmental effects of fertilization is also indicated. Information on benefits versus costs of large-scale fertilization is essential. The recent severalfold increase in cost of fertilizers and the uncertainty of future supplies are focusing attention on economics.

In southeast Alaska where forest management is presently not intensive, large-scale forest fertilization does not now appear to be justified. We would not encourage large-scale applications of fertilizer until more is known about the potential for response. Instead, studies should be directed toward gaining knowledge of the potential for thinning, combinations of thinning and fertilization, and fertilization of older stands where increases in growth could be realized in a short time.

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GPO 998-607

Farr, Wilbur A., A. S. Harris, and Spencer N. Israelson
1977. Effects of an aerial application of urea fertilizer on young Sitka spruce and western hemlock at Thomas Bay, Alaska. USDA Forest Serv. Res. Pap. PNW-219, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

In May 1969, about 1,500 acres (607 ha) of 6- to 10-year-old western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) were fertilized with agricultural grade urea at the rate of 400 pounds of urea per acre (448 kg/ha). No response in growth was detected the 1st year, but concentrations of nitrogen in the foliage about doubled. By 1971, nearly all hemlock on the fertilized and unfertilized areas was suffering from tip and leader dieback caused by the fungus *Sirococcus strobilinus*. Because of the fungus, hemlock growth could not be evaluated. Height and diameter growth of spruce increased 20 to 30 percent the second growing season. By the 5th or 6th year, there was little difference in growth, the net effect being that fertilized spruce were then about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than similar unfertilized trees.

KEYWORDS: Nitrogen fertilizer response, fertilizer (-natural regeneration, regeneration (natural), fertilizer application methods, spraying (aerial), increment (height), increment (diameter), Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, fungi (-forest damage, *Sirococcus strobilinus*.

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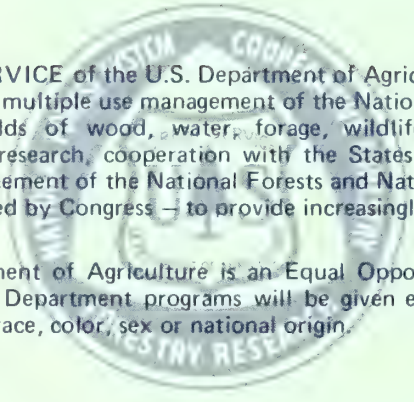

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# EFFECTS OF GRAVEL MORPHOLOGY ON FINE SEDIMENT INFILTRATION AND SURVIVAL OF INCUBATING SALMON EGGS

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CLEMSON UNIVERSITY
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# EFFECTS OF GRAVEL MORPHOLOGY ON FINE SEDIMENT ACCUMULATION AND SURVIVAL OF INCUBATING SALMON EGGS

Reference Abstract

Meehan, William R., and Douglas N. Swanston
1977. Effects of gravel morphlogy on fine sediment accumulation and survival of incubating salmon eggs. USDA For. Serv. Res. Pap. PNW-220, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Rate of fine sediment accumulation and survival of pink salmon eggs were determined for three types of stream gravels. At low stream flows, round gravel accumulated somewhat more sediment than other gravel types, while at higher discharges angular gravel accumulated more sediment. Survival of pink salmon eggs was slightly higher in angular gravel.

KEYWORDS: Sedimentation, gravel, fish habitat, salmon, streamflow.

## RESEARCH SUMMARY

Research Paper PNW-220

1977

Sediment entering streams as a result of natural or man-caused phenomena can result in decreased salmon egg survival. The influences of gravel shape and stream discharge on rate of sedimentation of gravels, and the effect of gravel shape on survival of pink salmon eggs were studied in East Creek and an adjacent artificial stream channel on Admiralty Island in southeast Alaska.

Two separate experiments were conducted, one to evaluate the short term accumulation of fine sediment under different waterflow conditions as affected by gravel shape, and the second to relate gravel shape to long term fine sediment accumulation and to survival of incubating salmon embryos. Angular and round gravel were tested as well as the natural gravel from East Creek which was somewhat platy.

The short term experiments were run in the artificial channel at different stream discharges. Known amounts of sediment were added to the channel water and accumulation in the various gravel types was determined. At very low flows round gravel accumulated somewhat more sediment than did angular gravel, while at higher discharges the relationship was reversed.

The long term experiments were conducted in both the artificial channel and the adjacent natural stream. Wire-meshed baskets simulating salmon "redds" were filled with gravel and a known number of fertilized pink salmon eggs. In these tests, which were run at fluctuating streamflows, more fine sediment accumulated in the angular gravel type. Salmon egg survival in the early stages also appeared to be slightly higher in the angular gravel. Survival in all gravel types was considerably higher in the baskets located in the artificial stream channel than in baskets located in the natural stream.

## INTRODUCTION

Sediment entering streams is a consequence of natural geologic erosive processes and of certain disturbances due to man's activities. Southeast Alaska is a geologically youthful topography in which mass soil movements and valley and stream development occur. These natural processes create sediment. Steep slopes and high rainfall make the land sensitive to accelerated sediment production from road construction and logging (Swanston 1974).

The main detrimental effect of fine sediment to fish habitat is due to the reduced permeability of gravel by water during the time of egg and fry development. As fine sediment accumulates in streambed gravels, the flow of water is reduced and the ability of water to carry away embryo metabolic wastes is decreased. In addition, fine sediment may form a physical barrier to emergence of fry from subsurface gravels to surface waters (Phillips 1971).

Over the past 60 years, the basic concepts concerning mechanics of streamflow and the effects of various stream parameters (e.g. depth, gradient, velocity, bedload, channel configuration) on sediment transport and deposition have been developed (Gilbert 1914, Rubey 1938, Kalinske 1947, Brooks 1958, Colby 1961). Attempts have also been made to apply these concepts to an analysis of the effects of transported sediments on survival of salmon eggs and alevins (Cooper 1965, Gangmark and Bakkala 1960). The results of these studies indicate a direct relationship between stream sedimentation and decrease in salmon egg survival.

The principles relating stream variables to sediment transport and deposition were developed from observations and measurements of streams in watersheds much older geomorphologically than those common to southeast Alaska. The channel gradients and water velocities were much lower and the flows more constant, and the sediment loads were finer in particle size than in Alaskan streams. Consequently, the quantitative results cannot be applied directly to conditions in southeast Alaska.

## DESCRIPTION OF STUDY AREA

The study was conducted in the East Creek watershed located on the northeastern shore of Admiralty Island in southeast Alaska (fig. 1). East Creek flows through mature, old-growth Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) forest, and empties into Young Bay.

An artificial stream channel (fig. 2) was constructed from fabricated black iron culvert material and located adjacent to East Creek. The channel is 30 m long and 2.1 m wide at a distance of 30.5 cm from the bottom, tapering to a width of 2.4 m at the top. The channel is 1.2 m deep and has a gradient of 3.3 percent. Gravel from the East Creek flood plain was used initially to fill the channel to a depth of 46 cm. A water control dam fabricated from rock-filled gabions and a wooden flume to transport water to the artificial channel were constructed on East Creek about 60 m above the channel (fig. 3). A stilling basin was dug at the lower end of the wooden intake flume and lined with nylon-reinforced polyvinyl sheeting. A 120° V-notch sharp-crested weir was built into the intake box of the artificial channel at the lower end of the stilling basin so that waterflow into the channel could be measured (fig. 4). On the east side of the stilling basin, another wooden flume transported excess water back into East Creek. A gage house was installed in the basin to house stage and water temperature recorders (fig. 4).

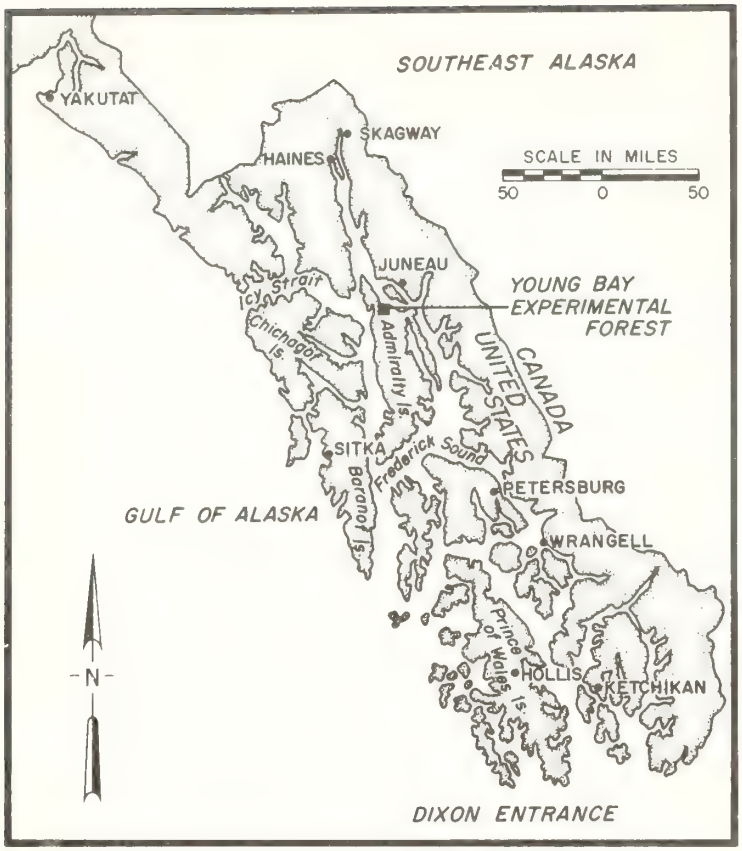


*Figure 1.--Map of southeast Alaska showing location of Young Bay Experimental Forest.*

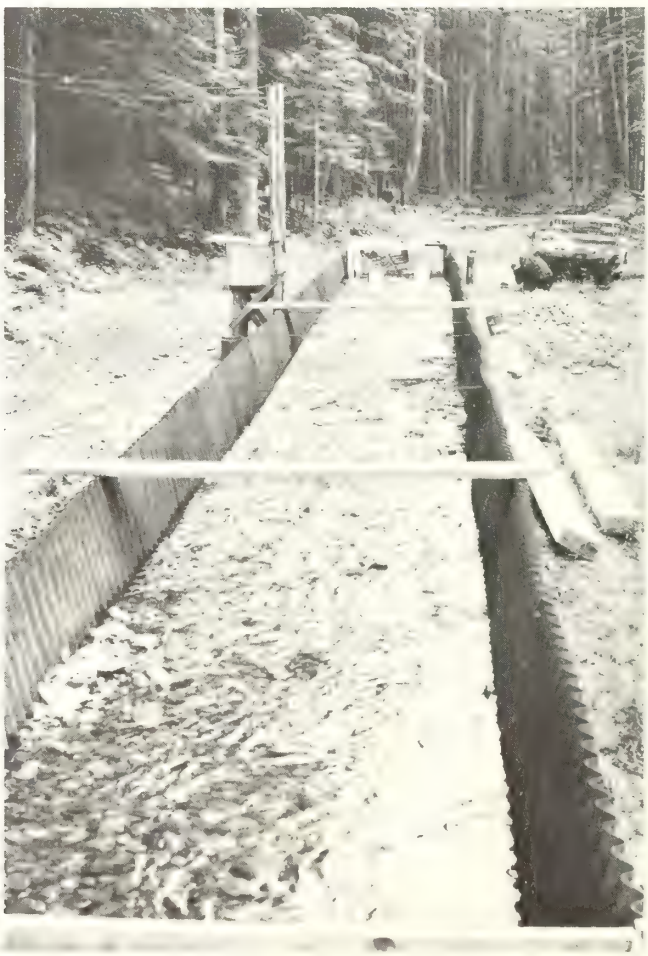

*Figure 2.--Artificial stream channel, looking downstream.*

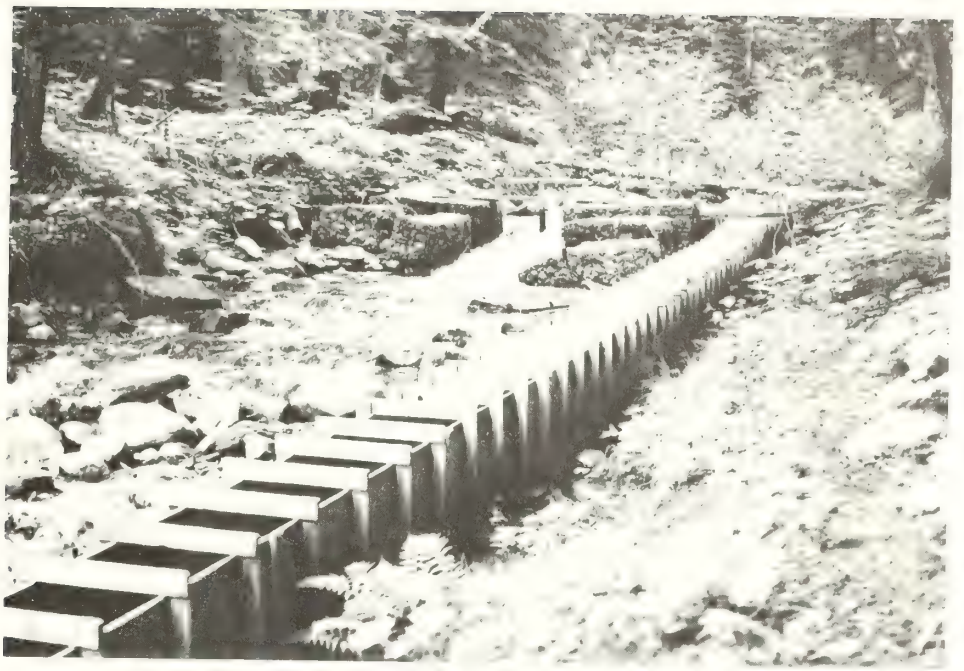

*Figure 3.--Gabion dam and intake flume.*

*Figure 4.--Intake flume, stilling basin, and outlet to channel showing V-notch weir and gage house.*

## METHODS

Two separate experiments were conducted; one to evaluate the short term accumulation of fine sediment under different waterflow conditions as affected by gravel shape and the second to relate gravel shape to long term fine sediment accumulation and to survival of incubating salmon embryos.

### Short Term Fine Sediment Accumulation

Gravels varying from 2.54 to 10.16 cm in diameter were hand picked and separated into *angular* and *round* classes. The gravel came from a presently dry portion of the channel of East Creek. The selected dry gravels were placed in number 10 cans, weighed, and then buried just below the "gravel pavement" layer in the experimental stream channel. Water was then conducted into the channel and flows brought to designated levels until a steady flow was reached. In 1971, four experimental runs were made at flow rates of 0.65 $m^3/s$, 0.41 $m^3/s$, 0.235 $m^3/s$, and 0.145 $m^3/s$. Two additional runs were made in 1973 at 0.80 $m^3/$ and 0.57 $m^3/s$. Experimental procedure was as follows:

a) Flow rate to be sampled was allowed to stabilize in the test section and was allowed to run until erosion armor formed and observable bedload transport ceased.

b) The flow was then stopped and 10 sample cans, 5 with angular gravel and 5 with round gravel, were buried in the test section with the ca mouths below the armor and the gravel flush at the surface of the channel (fig. 5)

Approximately 104 kg of fine sediment <2.0 mm (in the short

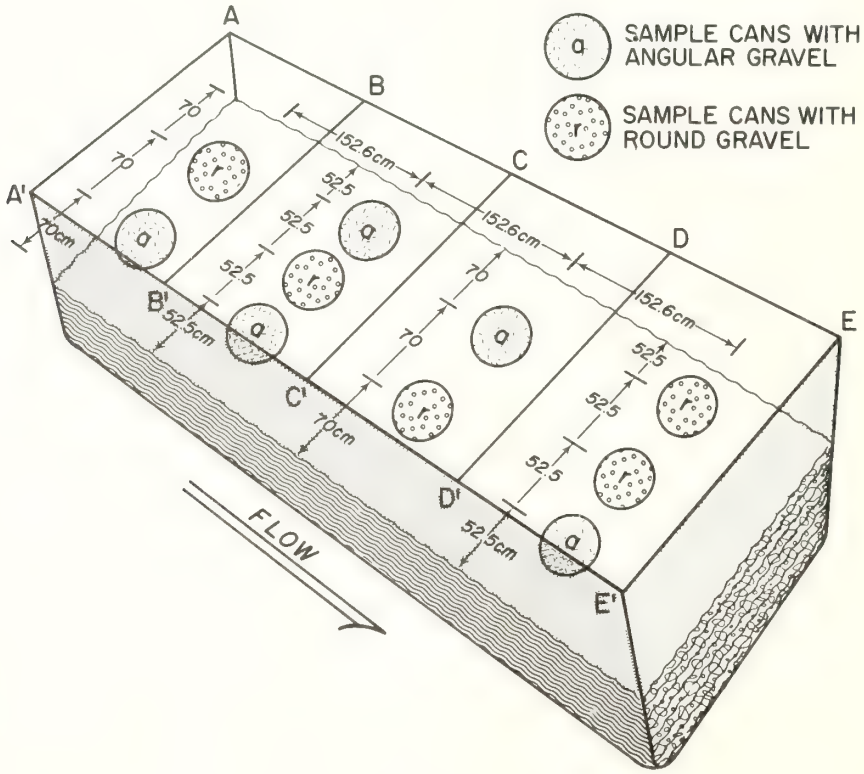


*Figure 5.--Diagram of test section showing dimensions and location of sediment sample cans.*

term experiments, fine sediment is less than 2.0 mm) were then added at the weir entrance, and the steady rate of flow maintained for 3 hours. The gravel-filled cans were then removed, oven-dried, and weighed to determine the amount of added sediment which accumulated during the duration of flow. Preliminary tests indicated that if these experiments were run at decreasing discharge rates, the "erosion pavement" or "rock armor" developed on the gravel surface was adequate to preclude fine sediment transport in the channel and into the cans prior to addition of the finer sediment. Disturbance resulting from burial of the sample cans was kept to a minimum and is not believed to have appreciably affected the sediment measurements.

### Long Term Fine Sediment Accumulation and Salmon Egg Survival

Ten stainless steel-mesh cylinders, each 45.7 cm deep and 30.5 cm in diameter were fabricated to serve as artificial "redds" (fig. 6).

Three gravel types were used in this portion of the study:

1) Round, stream-washed gravel 2.54 to 10.16 cm in diameter, composed primarily of argillite and greenstone.
2) Broken angular gravel, 2.54 to 10.16 cm in diameter, composed mainly of quartzite.
3) Natural gravel from East Creek, which was made up of the above types and which was somewhat platy in form.

The round and angular gravels were the same type as those used in the short term fine sediment accumulation tests (in the long term experiments, fine sediment is less than 0.833 mm).

*Figure 6.--Basket used as artificial "redd" and outer casing for retaining sediment when basket was removed from streambed.*

Enough pink salmon females to furnish 20,000 eggs were spawned in Auke Creek, a small stream about 24 km from the study area, in September, 1969, and again in September, 1970. The eggs, as well as milt from several males, were transported to Young Bay in insulated ice-packed chests. At the study site, the eggs were then fertilized and 2,000 eggs were added to each cylinder of gravel. Cylinders were identified by attaching stamped tags and were set into the artificial channel and the streambed so the tops of the cylinders were flush with the gravelbed surface. Continuous recording thermographs located in a gage house on East Creek (1969-70) and at the artificial channel site (1970-71) were used to monitor accumulation of temperature units by the incubating eggs.

During the winter of 1969-70, 10 samples of East Creek gravel had been taken from the streambed where egg cylinders were to be installed. A total of 10 baskets containing fertilized eggs and natural East Creek gravel (4 baskets), rounded gravel (3 baskets), or angular gravel (3 baskets) were then planted in the streambed.

During the winter of 1970-71, fine sediment which accumulated in the egg baskets in the artificial channel was evaluated by installing seven egg cylinders in the channel and three in East Creek to act as controls. One of the baskets in the channel contained natural East Creek gravel, three contained round gravel, and three contained angular gravel. The control baskets in East Creek consisted of one basket each of the three gravel types. Before the baskets were removed from the artificial channel to determine egg survival, the water to the channel was shut off and the intragravel water permitted to drain out. This allowed the baske to be removed without loss of fine sediments from flushing.

The material in the baskets du ing both tests was sorted by mean of standard Tyler sieves and then each size class was weighed.

Percent survival of eggs was determined by removing the cylind from the streambed after sufficie temperature units had accumulated for the eggs to reach the eyed st and be counted. Due to the diffi culty of access to the study site during the severe winter months, the eggs could not be maintained through to hatching.

The data from the 1969-70 test were not subjected to analysis of variance due to missing observati and frequent zeros. Data from th 1970-71 test were subjected to an analysis of variance.

## RESULTS

### Short Term Fine Sediment Accumulation

The effects of the measured ra of discharge and gravel shape on fine sediment accumulation are summarized in table 1 and figures and 8. At flows within the range of our experiment, 0.145 to 0.80 $m^3$ per s, it appears that accu lation of fine sediment increases angular gravels with increasing discharge (fig. 7). Conversely, round gravels show a correspondin decrease (fig. 8). This can be t result of several factors. The greater amount of fine sediment accumulated in the rounded gravel at low flows may be a reflection of the relative ease with which water moves around and over round gravels. In such a low energy situation, less tractive force is required to carry particles to fi interstices. As flow rates incre the water can transport more mate

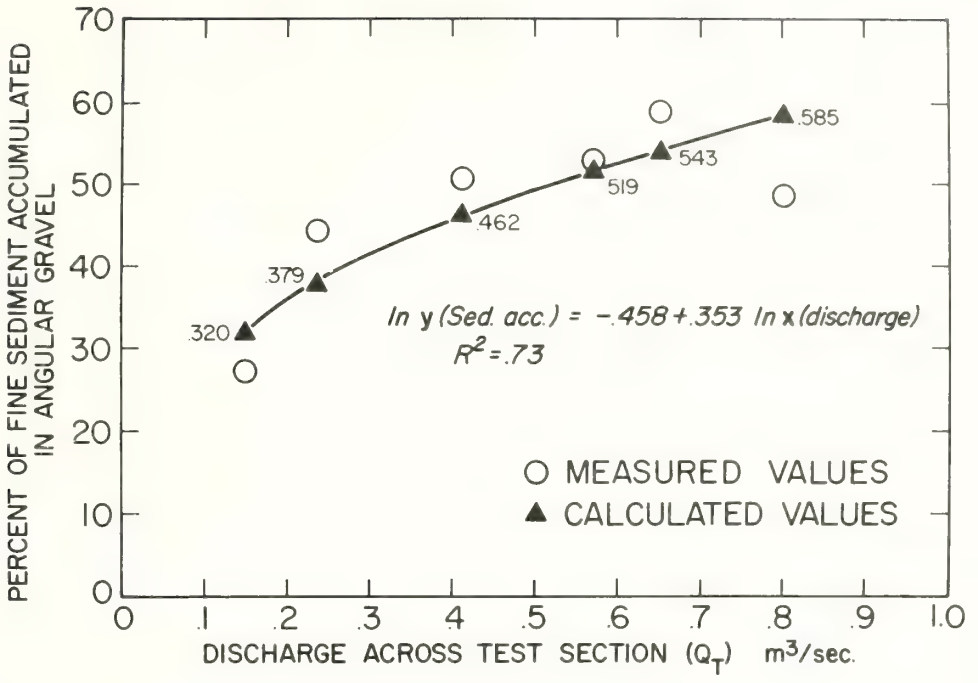


*Figure 7.--Accumulation of fine sediment vs. discharge across the test section for angular gravel.*

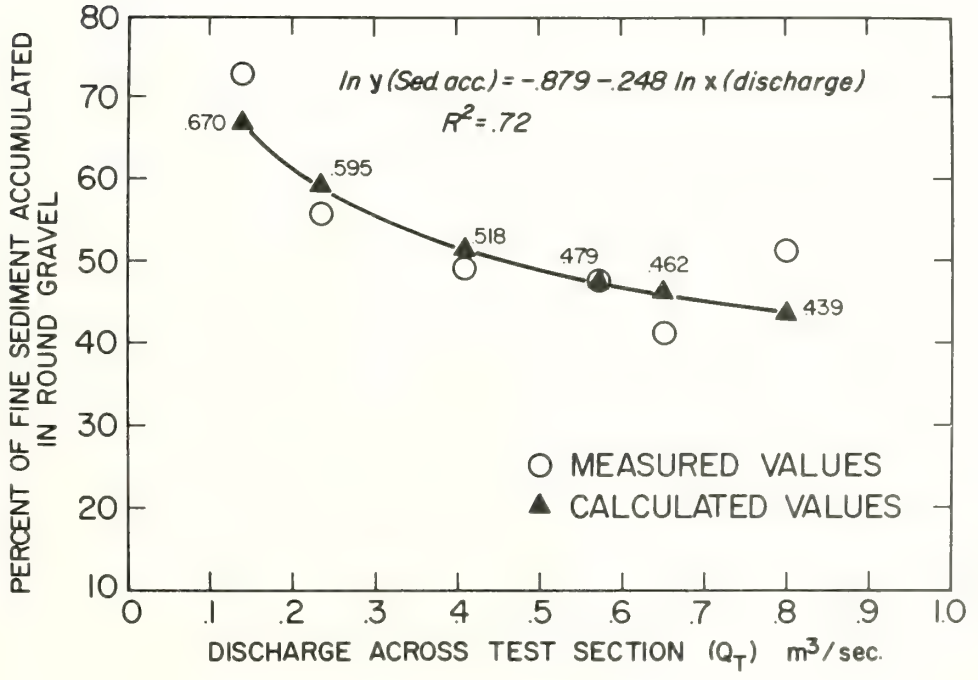


*Figure 8.--Accumulation of fine sediment vs. discharge across the test section for round gravel.*

Table 1--*Impact of discharge, tractive force, and particle shape on movement of channel materials in test section*

| $Q_T$ discharge test section | Tractive force 1/3 (W) | Total weight accumulated sediment | | Total weight accumulated sediment in test section | Total sediment accumulate | |
|---|---|---|---|---|---|---|
| | | Angular gravel | Round gravel | | Angular gravel | Round grav |
| $m^3/s$ | watts/$m^2$ | g | g | g | Percent | Percent |
| 0.145 | 7.44 | 727.7 | 1939.5 | 2667.2 | 27.3 | 72.7 |
| 0.235 | 12.06 | 1994.8 | 2516.3 | 4511.1 | 44.2 | 55.8 |
| 0.410 | 21.05 | 3005.0 | 2908.7 | 5913.7 | 50.8 | 49.2 |
| 0.57 | 29.26 | 2887.5 | 2631.5 | 5519.0 | 52.3 | 47.7 |
| 0.65 | 33.37 | 4331.9 | 3008.2 | 7340.1 | 59.0 | 41.0 |
| 0.80 | 41.07 | 5356.5 | 5622.6 | 10979.1 | 48.8 | 51.2 |

Greater turbulence, however, is generated around angular gravels, periodically producing local areas of zero or negative velocity, trapping particles, and increasing fine sediment accumulation in the angular gravels. Above 0.41 $m^3$ per s, more sediment accumulates in angular than round gravels although there appears to be a leveling off of the sediment accumulated in both gravel types.

## Long Term Fine Sediment Accumulation and Salmon Egg Survival

Weights and percentages by weight of fine sediments in size classes <0.833 mm which accumulated in the egg baskets are presented in tables 2-4 and in figures 9 and 10. From these data it is apparent that less fine sediment (<0.833 mm) accumulated in the natural East Creek gravel than in either round or angular selected gravel. One factor which probably contributed to this result is that the natural creek gravel had more material between 0.833 mm and 25 mm in size, and hence, less room for finer sediments. It also appears that more sediment <0.833 mm accumulated in angular gravel than in round gravel, again probably due to the availability of intragravel voids. Low stream flows during this long term experiment were recorded as 0.16 $m^3$ per s. Higher flows, however, and particularly storm flows probably accounted for higher sediment deposition in angular gravel. The natural East Creek gravels accumulated fine sediment in a direct relationship to size class, i.e., the finer the sediment, the less there was (both in weight and percent of total sediment). In the round and angular gravels, however, more sediment between 0.208 and 0.104 mm was generally evident than were other size classes.

During both winters that fertilized eggs were held in gravel baskets, problems were encountered which prevented them from living until hatching time. During the winter of 1969-70, artificial redds were placed in the streambed of East Creek. A severe flood during December 1969 scoured two baskets out of the streambed and washed them downstream and shifted several others. Most of the eggs in the baskets were killed at this time; however, many of the eggs had survived through the eyed stage. During the winter of 1970-71, seven egg baskets were placed in the artificial stream channel; three were placed in East Creek adjacent to the channel. During this winter, debris blocked the entrance to the water intake flume; and when the

Table 2--*Amount of bedload sediment by size class in East Creek, 1969-70*

| Sample No. | Amount of sediment in size class | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total <0.833 mm | | 0.417 - 0.833 mm | | 0.208 - 0.417 mm | | 0.104 - 0.208 mm | | <0.104 mm | |
| | g | Percent[1] | g | Percent | g | Percent | g | Percent | g | Percent |
| N1 | 44 | 1.30 | 32 | 0.95 | 6 | 0.18 | 3 | 0.09 | 3 | 0.09 |
| N2 | 208 | 5.55 | 166 | 4.43 | 31 | 0.83 | 9 | 0.24 | 2 | 0.05 |
| N3 | 150 | 6.06 | 122 | 4.93 | 20 | 0.81 | 6 | 0.24 | 2 | 0.08 |
| N4 | 79 | 2.50 | 59 | 1.87 | 13 | 0.41 | 6 | 0.19 | 1 | 0.03 |
| R1 | 211 | 6.89 | 177 | 5.78 | 26 | 0.85 | 5 | 0.16 | 3 | 0.10 |
| R2 | 120 | 2.46 | 100 | 2.05 | 14 | 0.29 | 4 | 0.08 | 2 | 0.04 |
| R3 | 72 | 1.58 | 60 | 1.32 | 9 | 0.20 | 2 | 0.04 | 1 | 0.02 |
| A1 | 79 | 2.11 | 68 | 1.82 | 7 | 0.19 | 2 | 0.05 | 2 | 0.05 |
| A2 | 334 | 7.34 | 238 | 5.23 | 71 | 1.56 | 22 | 0.48 | 3 | 0.07 |
| A3 | 138 | 3.50 | 96 | 2.43 | 25 | 0.63 | 13 | 0.33 | 4 | 0.10 |
| *Mean* | *143.5* | *3.93* | *111.8* | *3.08* | *22.2* | *0.60* | *7.2* | *0.19* | *2.4* | *0.06* |

1/ Percentages are based on entire sample, not just that portion less than 0.833 mm.

Table 3--*Amount of bedload sediment by size class accumulated in egg baskets in East Creek, 1969-70*

| asket No. | Amount of sediment in size class | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total <0.833 mm | | 0.417 - 0.833 mm | | 0.208 - 0.417 mm | | 0.104 - 0.208 mm | | <0.104 mm | |
| | g | Percent[1] | g | Percent | g | Percent | g | Percent | g | Percent |
| tal stream rvel | | | | | | | | | | |
| N1 | 453 | 5.38 | 223 | 2.65 | 98 | 1.16 | 61 | 0.72 | 71 | 0.84 |
| N2 | 302 | 5.12 | 174 | 2.95 | 72 | 1.22 | 30 | 0.51 | 26 | 0.44 |
| N3 | 595 | 6.09 | 310 | 3.17 | 104 | 1.06 | 124 | 1.27 | 57 | 0.58 |
| N4 | 365 | 3.84 | 128 | 1.35 | 82 | 0.86 | 67 | 0.70 | 88 | 0.93 |
| a N | *428.8* | *5.11* | *208.8* | *2.53* | *89.0* | *1.08* | *70.5* | *0.80* | *60.5* | *0.70* |
| ul gravel | | | | | | | | | | |
| R1 | 468 | 4.24 | 124 | 1.12 | 167 | 1.51 | 142 | 1.29 | 35 | 0.32 |
| R2 | 454 | 6.17 | 92 | 1.25 | 154 | 2.09 | 161 | 2.19 | 47 | 0.64 |
| R3 | 620 | 7.30 | 159 | 1.87 | 212 | 2.50 | 143 | 1.68 | 106 | 1.25 |
| a R | *514.0* | *5.90* | *125.0* | *1.41* | *177.7* | *2.03* | *148.7* | *1.72* | *62.7* | *0.74* |
| gar gravel | | | | | | | | | | |
| A1 | 432 | 5.69 | 95 | 1.25 | 89 | 1.17 | 115 | 1.51 | 133 | 1.75 |
| A2 | 647 | 6.23 | 124 | 1.19 | 135 | 1.30 | 173 | 1.67 | 215 | 2.07 |
| A3 | 581 | 6.48 | 204 | 2.28 | 112 | 1.25 | 186 | 2.07 | 79 | 0.88 |
| a A | *553.3* | *6.13* | *141.0* | *1.57* | *112.0* | *1.24* | *158.0* | *1.75* | *142.3* | *1.57* |

[1]Percentages are based on entire sample, not just that portion less than 0.833 mm.

Table 4--*Amount of bedload sediment by size class accumulated in egg baskets in artificial stream and in East Creek, 1970-71*

| Basket No.[1] | Amount of sediment in size class | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total <0.833 mm | | 0.417 - 0.833 mm | | 0.208 - 0.417 mm | | 0.104 - 0.208 mm | | <0.104 mm | |
| | g | Percent[2] | g | Percent | g | Percent | g | Percent | g | Percent |
| N | 624 | 5.40 | 318 | 2.75 | 120 | 1.04 | 99 | 0.86 | 87 | 0.75 |
| R | 687 | 5.72 | 196 | 1.63 | 225 | 1.87 | 203 | 1.69 | 63 | 0.52 |
| A | 718 | 6.21 | 189 | 1.63 | 166 | 1.44 | 197 | 1.70 | 166 | 1.44 |
| Natural stream gravel | | | | | | | | | | |
| N1 | 2748 | 4.96 | 1469 | 2.65 | 593 | 1.07 | 287 | 0.52 | 399 | 0.72 |
| Round gravel | | | | | | | | | | |
| R1 | 3927 | 7.87 | 984 | 1.97 | 1069 | 2.14 | 1056 | 2.12 | 818 | 1.64 |
| R2 | 5351 | 9.97 | 936 | 1.74 | 1282 | 2.38 | 1588 | 2.96 | 1545 | 2.88 |
| R3 | 5719 | 10.83 | 1216 | 2.30 | 1372 | 2.60 | 1725 | 3.27 | 1406 | 2.66 |
| *Mean R* | *4999* | *9.56* | *1045.3* | *2.00* | *1241.0* | *2.37* | *1456.3* | *2.78* | *1256.3* | *2.39* |
| Angular gravel | | | | | | | | | | |
| A1 | 6458 | 14.16 | 1428 | 3.13 | 1629 | 3.57 | 1839 | 4.03 | 1562 | 3.43 |
| A2 | 4610 | 10.02 | 1150 | 2.50 | 1178 | 2.56 | 1225 | 2.66 | 1057 | 2.30 |
| A3 | 6128 | 13.60 | 1252 | 2.78 | 1353 | 3.00 | 1734 | 3.85 | 1789 | 3.97 |
| *Mean A* | *5732* | *12.59* | *1276.7* | *2.80* | *1386.7* | *3.04* | *1599.3* | *3.51* | *1469.3* | *3.23* |

[1]Baskets N, R, and A were tested in East Creek. All others were tested in the artificial stream channe
[2]Percentages are based on entire sample, not just that portion less than 0.833 mm.

flow decreased in the artificial stream, the intragravel water, as well as remaining surface water, froze. Again, many of the eggs which had survived to the eyed stage died. As a result, the survival figures presented in tables 5 and 6 represent survival to eyeing. For example, during 1969-70, out of 1,894 eggs which were examined in basket N3, 775 (40.9 percent) reached the eyed stage (table 5). Since in both years the baskets were retrieved before temperature units necessary for hatching had accumulated but well after temperature units necessary for eyeing had accumulated, the discrepancies in final numbers of eggs counted from those originally placed in the baskets are open to speculation. Part of these discrepancies may be explained by unfertilized or otherwise dead eggs which broke up and disintegrated soon after the artificial spawning process. In some cases the baskets had been forced open during severe shifting and some eggs were undoubtedly lost The assumption here is that there was no difference in the loss of eggs from the baskets between those which had reached the eyed stage and those which had not.

The egg survival figures presented in tables 5 and 6 are based not on the total number of eggs originally placed in the baskets (approximately 2,000 eggs per basket) but rather on the percentage of the remaining eggs which had reached the eyed stage. For example in table 5 the number of remaining eggs which had reached the eyed stage in basket A2 is 206 out of a total of 249 remaining eggs, or 82.7 percent. If, however, this survival to eyed stage had been based on total number of eggs

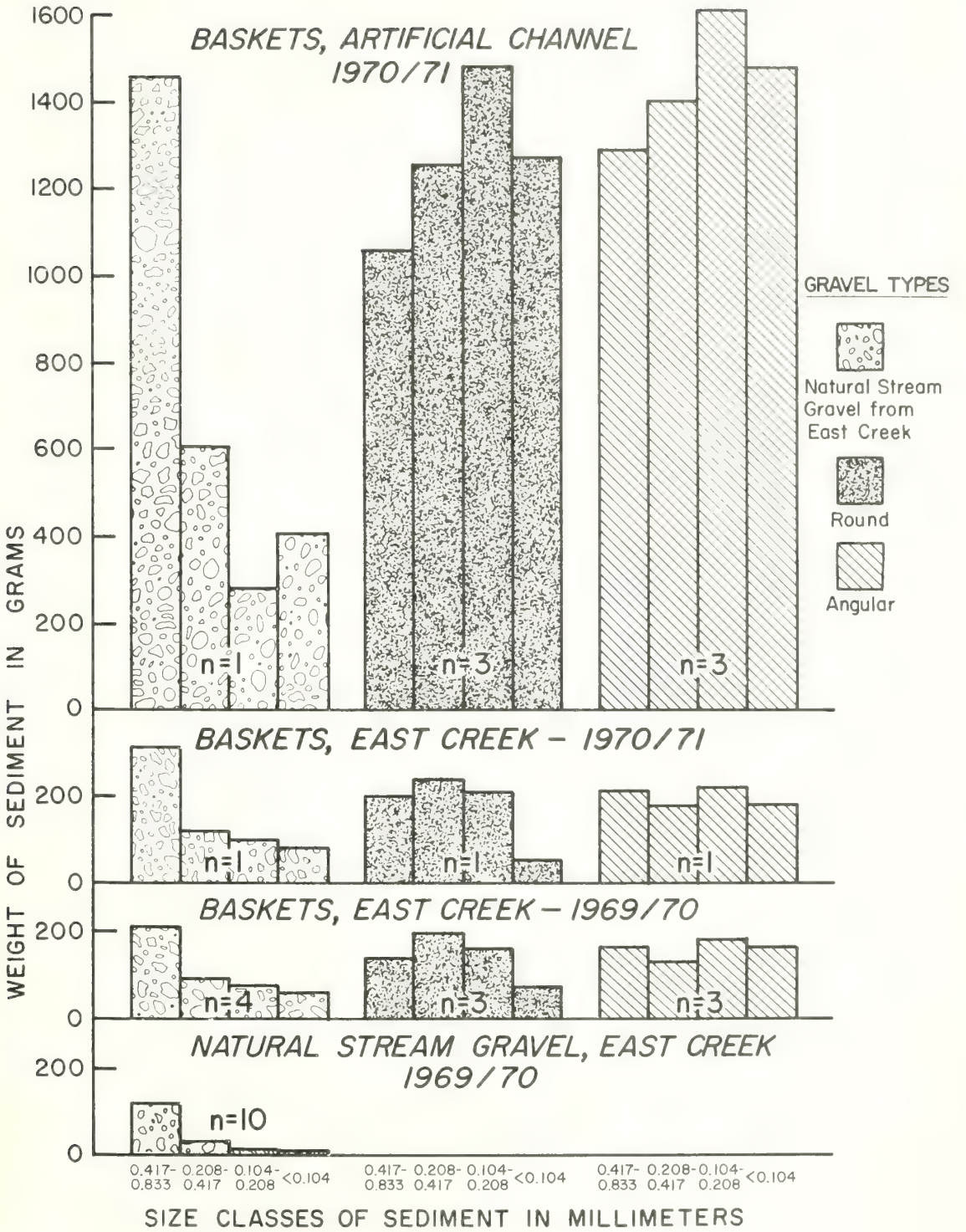


*Figure 9.--Weight of bedload sediment which accumulated in egg baskets containing various gravel types, located in East Creek (1969-70 and 1970-71) and in artificial stream channel (1970-71).*

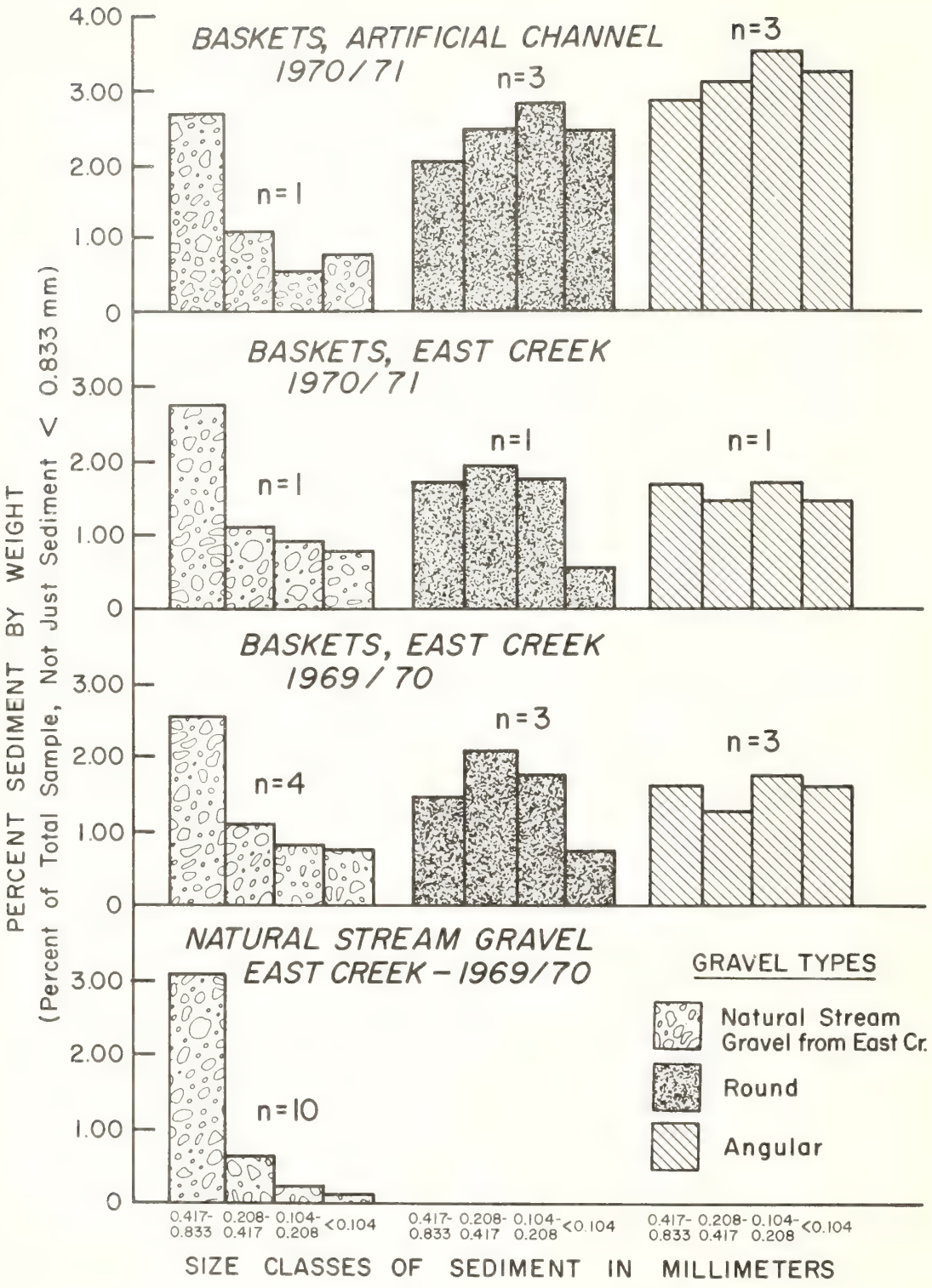


*Figure 10.--Percent by weight of bedload sediment which accumulated in egg baskets containing various gravel types, located in East Creek (1969-70 and 1970-71) and in artificial stream channel (1970-71).*

Table 5--*Survival of remaining pink salmon eggs to eyed stage in artificial redds containing round, angular, or natural stream gravels, East Creek, 1969-70*

| Basket number | Gravel type | Number of eggs counted | | Percent survival to eyed stage |
|---|---|---|---|---|
| | | Live[1] | Dead[2] | |
| N1 | Natural stream | 0 | 1,000 | 0.0 |
| N2 | Natural stream | [3] | -- | -- |
| N3 | Natural stream | 775 | 1,119 | 40.9 |
| N4 | Natural stream | 50 | 500 | 9.1 |
| R1 | Round | 0 | 1,850 | 0.0 |
| R2 | Round | 0 | 1,600 | 0.0 |
| R3 | Round | [3] | -- | -- |
| A1 | Angular | 0 | 900 | 0.0 |
| A2 | Angular | 206 | 43 | 82.7 |
| A3 | Angular | 43 | 24 | 64.2 |

[1]Live eggs are those which lived at least to eyed stage.
[2]Dead eggs are those which did not live to eyed stage.
[3]Basket washed out of streambed.

Table 6--*Survival of remaining pink salmon eggs to eyed stage in artificial redds containing round, angular, or natural stream gravels, 1970-71*

| Basket number | Location | Gravel type | Number of eggs counted | | Percent survival to eyed stage |
|---|---|---|---|---|---|
| | | | Live[1] | Dead[2] | |
| N | East Creek | Natural stream | 24 | 273 | 8.1 |
| R | East Creek | Round | 38 | 393 | 8.8 |
| A | East Creek | Angular | 7 | 520 | 1.3 |
| N1 | Artificial stream channel | Natural stream | 987 | 355 | 73.5 |
| R1 | Artificial stream channel | Round | 1,197 | 235 | 83.6 |
| R2 | Artificial stream channel | Round | 1,280 | 320 | 80.0 |
| R3 | Artificial stream channel | Round | 1,381 | 420 | 76.7 |
| A1 | Artificial stream channel | Angular | 1,615 | 240 | 87.1 |
| A2 | Artificial stream channel | Angular | 1,360 | 325 | 80.7 |
| A3 | Artificial stream channel | Angular | 1,444 | 470 | 75.4 |

[1]Live eggs are those which lived at least to eyed stage.
[2]Dead eggs are those which did not live to eyed stage.

originally put into the basket (2,000), it would have been only 10.3 percent.

Results in table 6 show no significant difference among mean survival in natural, round, and angular gravels (73.50, 80.10, and 81.07, respectively). In the absence of a statistical analysis of the data in table 5, it is not possible to draw any meaningful conclusions about the preferability of one gravel type over another for survival of salmon embryos, although the angular gravel may have provided slightly better survival. It is obvious from tables 5 and 6, however, that considerably higher survival was obtained in the artificial channel than in the natural stream.

Table 7 compares egg survival with total amount of sediment <0.833 mm which accumulated in the baskets during the winter of 1969-70 in East Creek. Table 8 makes a similar comparison for baskets tested during the winter of 1970-71 in East Creek and in the artificial stream channel. The most significant results are that the egg survivals in the baskets in the channel were almost 10 times those of eggs which incubated in baskets in East Creek, and the amount of fine sediments which accumulated in channel baskets was about 10 times greater than amount of fine sediment which accumulated in East Creek baskets (table 8). Several factors may have contributed to these results. The much more even (controlled) water flow in the artificial stream should be directly correlated with egg and alevin survival, primarily because of the reduced probability of shock particularly during the "tender" periods of egg development. The fact that more fine sediment accumulated in baskets in the artificial stream than in baskets in East Creek (in all three gravel types tested) may be explained in part by the fact that the gabion dam at the head of the artificial structure tended to promote deposition of fine sediment in front of the dam in the area of the intake flume. During periods of high flow this sediment accumulation may have been washed into the channel in comparatively greater quantities than passed down East Creek itself.

Much less dramatic results were obtained from comparing sediment accumulation and egg survival among gravel types, although it appears that, in general, the least amount of fine sediment accumulated in natural stream gravel and the most in angular gravel. This is probably due to space available for accumulation and also to the "paving" effect of natural East Creek gravel. Also it appears that somewhat higher survival occurred in the angular gravel. The differences, however, in both fine sediment accumulation and egg survival between round and angular gravels are very small.

Table 7--*Egg survival and fine sediment accumulation in baskets in East Creek, 1969-70*

| Basket number | Gravel type | Egg survival | Fine sediment (<0.833 mm) | |
|---|---|---|---|---|
| | | Percent[1] | g | Percent |
| N1 | Natural stream | 0 | 453 | 5.38 |
| N2 | Natural stream | [2] | 302 | 5.12 |
| N3 | Natural stream | 40.9 | 595 | 6.09 |
| N4 | Natural stream | 9.1 | 365 | 3.84 |
| *Mean N* | | *16.7* | *428.8* | *5.11* |
| R1 | Round | 0 | 468 | 4.24 |
| R2 | Round | 0 | 454 | 6.17 |
| R3 | Round | [2] | 620 | 7.30 |
| *Mean R* | | *0* | *514.0* | *5.90* |
| A1 | Angular | 0 | 432 | 5.69 |
| A2 | Angular | 82.7 | 647 | 6.23 |
| A3 | Angular | 64.2 | 581 | 6.48 |
| *Mean A* | | *49.0* | *553.3* | *6.13* |

[1]Survival of remaining eggs to eyed stage.
[2]Eggs washed out during flood.

Table 8--*Egg survival and fine sediment accumulation in baskets in East Creek and in artificial stream channel, 1970-71*

| Basket number[1] | Gravel type | Egg survival | Fine sediment (<0.833 mm) | |
|---|---|---|---|---|
| | | Percent[2] | g | Percent |
| N | Natural stream | 8.1 | 624 | 5.40 |
| R | Round | 8.8 | 687 | 5.72 |
| A | Angular | 1.3 | 718 | 6.21 |
| N1 | Natural stream | 73.5 | 2748 | 4.96 |
| R1 | Round | 83.6 | 3927 | 7.87 |
| R2 | Round | 80.0 | 5351 | 9.97 |
| R3 | Round | 76.7 | 5719 | 10.83 |
| *Mean R* | | *80.1* | *4999* | *9.56* |
| A1 | Angular | 87.1 | 6458 | 14.16 |
| A2 | Angular | 80.7 | 4610 | 10.03 |
| A3 | Angular | 75.4 | 6128 | 13.60 |
| *Mean A* | | *81.1* | *5732* | *12.59* |

[1]Baskets N, R, and A were tested in East Creek. All others were tested in the artificial stream channel.
[2]Survival of remaining eggs to eyed stage.

## CONCLUSIONS

The results of this study suggest that in the absence of storm flows, gravel shape can have an appreciable effect on short term sediment accumulation in spawning gravels. This is particularly evident for flow rates $<0.8$ $m^3$ per s (rates within our experimental range).

At very low flows, $<0.2$ $m^3$ per s, round gravels tend to accumulate more fine sediment than angular gravels. This relationship is reversed as flow rates increase above approximately 0.4 $m^3$ per s and angular gravels tend to accumulate more sediment.

When fertilized salmonid eggs are "planted" in artificial containers, survival appears to be potentially greater if they are placed in a structure in which streamflow can be controlled than when they are placed in a natural streambed subject to storm flows and consequent gravel disturbance.

Survival of salmonid embryos, at least in the early stages of development, may be somewhat greater in angular gravels than in other gravel types. Since the amount of fine sediment which accumulates during a range of water flow conditions is somewhat greater in angular gravels than in other gravel types, embryo survival may at times be highest in those gravels containing the most fine sediment; this situation is probably due to other factors such as amount of intragravel void space, water velocity, etc.

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1977. Effects of gravel morphology on fine sediment accumulation and survival of incubating salmon eggs. USDA For. Serv. Res. Pap. PNW-220, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Rate of fine sediment accumulation and survival of pink salmon eggs were determined for three types of stream gravels. At low stream flows, round gravel accumulated somewhat more sediment than other gravel types, while at higher discharges angular gravel accumulated more sediment. Survival of pink salmon eggs was slightly higher in angular gravel.

KEYWORDS: Sedimentation, gravel, fish habitat, salmon, streamflow.

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Meehan, William R., and Douglas N. Swanston
1977. Effects of gravel morphology on fine sediment accumulation and survival of incubating salmon eggs. USDA For. Serv. Res. Pap. PNW-220, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

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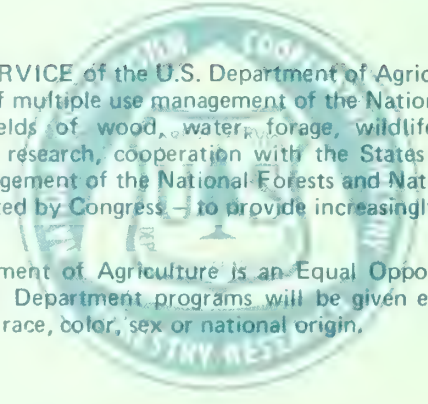

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1977
USDA FOREST SERVICE RESEARCH PAPER PNW-221

# LEVELS-OF-GROWING-STOCK STUDY IN THINNED WESTERN LARCH POLE STANDS IN EASTERN OREGON

K.W. SEIDEL

SEP 3 1977
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US DEPARTMENT OF AGRICULTURE, FOREST SERVICE
PORTLAND, OREGON

## Metric Conversions

1 mile = 1.61 km
1 foot = 0.3048 m
1 inch = 2.54 cm
1 acre = 0.4047 ha
1 square foot per acre = 0.2296 square meters per hectare
1 cubic foot per acre = 0.0700 cubic meters per hectare

## Acknowledgment

WALTER G. DAHMS, formerly with the Pacific Northwest Forest and Range Experiment Station and now retired, was responsible for the design and installation of this study.

# LEVELS-OF-GROWING-STOCK STUDY IN THINNED WESTERN LARCH POLE STANDS IN EASTERN OREGON

*Reference Abstract*

Seidel, K. W.
1977. Levels-of-growing-stock study in thinned western larch pole stands in eastern Oregon. USDA For. Serv. Res. Pap. PNW-221, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

The 10-year growth response from a levels-of-growing-stock study in an even-aged western larch stand in eastern Oregon, first thinned at age 33, showed that trees growing at lower stand densities grew more rapidly in diameter but did not grow faster in height than trees in high density plots. Both basal area and total cubic volume increment increased as stand density increased. Despite the large reduction in volume increment at the lower densities, most of the wood, however, is concentrated on a fewer number of faster growing trees that can reach usable size sooner.

KEYWORDS: Growing stock (-increment/yield, thinnings (-stand volume, stand density, forest improvement cutting, stand improvement, increment (diameter), increment (basal area), increment (stand volume), western larch, Oregon (eastern).

*RESEARCH SUMMARY*

*Research Paper PNW-221*

*1977*

A levels-of-growing-stock study was installed in a 33-year-old even-aged western larch stand in 1966 for the purpose of providing basic growth and yield information over a wide range of stocking levels. The study is located in eastern Oregon in a seral larch stand typical of the *Abies grandis/Calamagrostis rubescens* plant community. The plots were precommercially thinned from below to five density levels expressed as thousands of square feet of bole area per acre.

Diameter growth was significantly affected by stand density, increasing as growing-stock level decreased. During the 10-year period after thinning, growth increased average stand diameter by 3.4 inches in low density plots compared with a 1.0-inch increase in high density plots. Height growth was insensitive to changes in stand density, and mortality was negligible. Both basal area and total cubic volume increment increased significantly as stand density increased. Although total volume growth was greatest in high density plots, wood is added more rapidly to a smaller number of potentially usable trees in the low density plots. Board-foot growth was greatest in the low density plots because of the large amount of ingrowth from trees reaching merchantable size.

Bole area was found to be a satisfactory measure of stand density. A constant bole area level resulted

in a rising level of basal area as the stand grew older. Basal area and number of trees per acre equivalents for bole area levels are given by average stand diameter for land managers wishing to use bole area as a measure of stand density.

Evidence from other studies suggests that the ideal time for precommercially thinning overstocked larch stands is around 10 to 15 years of age before crowns have begun to shorten and before diameter and height growth is slowed. As demonstrated in this study, however, considerable gains are still possible from precommercial thinnings in larch stands up to 30 years of age and 45 feet tall. The proper intensity of thinning depends not only upon timber management objectives, but also upon the importance to the land manager of other forest resources. In terms of timber management, the primary factor influencing the residual stocking level is the forester's estimate of the minimum size tree (d.b.h.) that will be merchantable in the future. The larger the trees must be to support a commercial thinning, the fewer trees should be left after precommercial thinning; and conversely, if smaller trees are merchantable, the residual stocking should be higher.

Western larch (*Larix occidentalis* Nutt.) is a valuable seral species in the mixed conifer forests of northeastern Oregon because of its fast growth rate and desirable wood properties. Even-aged larch stands generally become established following fire or other forest disturbances. These stands are often heavily overstocked as seedlings.

Stand density control by thinning is an essential part of the management of young larch stands. Because of the shade intolerance of larch, tree crowns in unthinned stands are reduced in size resulting in a decrease in rates of diameter and height growth as early as 9 years of age (Schmidt 1966). The increasing utilization of larch and other species and the associated intensification of forest management raises questions regarding suitable stocking level regimes for managed larch stands.

Although some information is available on the response of larch to thinning from studies in Montana and British Columbia (Roe and Schmidt 1965, Illingworth 1964, Thompson 1969), there is no long-term data on the growth response of managed stands to various growing stock levels. Basic growth and yield data over a rotation is needed so forest managers can design thinning schedules to meet timber production and multiple use objectives.

This paper presents 10-year-growth results from a levels-of-growing-stock study begun in 1966 in northeastern Oregon. The study was designed to provide basic information on the growth response of young even-aged larch stands to a wide range of stocking levels. The first 5-year results from this study were reported by Seidel (1971).

## Study Area and Methods

The study is located on the Union District of the Wallowa-Whitman National Forest about 15 miles southeast of Union, Oregon at an elevation of about 4,000 feet. The stand was 33 years old in 1966 and has a site index of about 80 feet at age 50.[1/]

All plots were well stocked before the initial thinning, each containing at least 25,000 square feet of bole area per acre (table 1). There were about 1,300 trees per acre averaging 4.5 inches d.b.h. and 45 feet tall. All plot trees are larch except for one plot at the highest density level and one plot at the second highest level where about 40 percent of the bole area and basal area left after the initial thinning was lodgepole pine (*Pinus contorta* Dougl.).

The soil is a Tolo silt loam, which is a well-drained Regosol developed from dacite pumicite originating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. It is underlain at a depth of about 3 feet by a buried soil developed from basalt.

Ground vegetation on the study area is typical of the *Abies grandis/ Calamagrostis rubescens* plant community (Franklin and Dyrness 1973). Genera of shrubs and herbs such as *Arnica*, *Hieracium*, and *Ribes* are common.

The experiment is a levels-of-growing-stock study designed for thinning at 10-year intervals. The experiment consists of a completely randomized design with two replicates of five levels-of-growing-stock randomly assigned to each of ten 0.4-acre plots. The growing-stock levels selected for testing are 5,000; 10,000; 15,000; 20,000; and

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[1/] Site index based on curves in "Ecology and Silviculture of Western Larch Forests," by Wyman C. Schmidt et al. (1976).

Table 1--*Stand characteristics per acre of western larch before and after the 1966 and 1976 thinnings and in 1971*

| Density level | Bole area | Basal area | Number of trees | Average spacing | Quadratic mean diameter | Average height[1/] | Volume[2/] | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total | Merchantable including ingrowth | |
| | Square feet | | | Feet | Inches | Feet | Cubic feet | Cubic feet | Board feet |
| Before initial (1966) thinning: | | | | | | | | | |
| 1 | 25,800 | 118.6 | 924 | 6.9 | 4.9 | 48.4 | 1,995 | 1,180 | 48 |
| 2 | 31,125 | 132.7 | 1,161 | 6.1 | 4.6 | 46.2 | 2,287 | 1,088 | -- |
| 3 | 34,180 | 139.2 | 1,406 | 5.6 | 4.3 | 46.5 | 2,367 | 885 | 193 |
| 4 | 32,880 | 143.7 | 1,377 | 5.6 | 4.4 | 42.9 | 2,322 | 1,125 | -- |
| 5 | 32,700 | 135.6 | 1,459 | 5.5 | 4.1 | 42.0 | 2,200 | 964 | -- |
| Average | 31,337 | 134.0 | 1,265 | 5.9 | 4.5 | 45.2 | 2,234 | 1,048 | 48 |
| After 1966 thinning: | | | | | | | | | |
| 1 | 4,708 | 26.0 | 96 | 21.3 | 7.0 | 48.4 | 474 | 389 | 48 |
| 2 | 9,524 | 49.6 | 215 | 14.2 | 6.5 | 46.2 | 902 | 648 | -- |
| 3 | 14,242 | 70.9 | 355 | 11.1 | 6.1 | 46.5 | 1,272 | 782 | 193 |
| 4 | 19,313 | 96.4 | 546 | 8.9 | 5.7 | 42.9 | 1,616 | 1,039 | -- |
| 5 | 24,203 | 109.8 | 745 | 7.6 | 5.2 | 42.0 | 1,847 | 961 | -- |
| 1971: | | | | | | | | | |
| 1 | 6,374 | 40.3 | 96 | 21.3 | 8.8 | 55.4 | 794 | 678 | 948 |
| 2 | 12,069 | 68.2 | 215 | 14.2 | 7.6 | 51.7 | 1,333 | 1,060 | 294 |
| 3 | 17,797 | 93.4 | 354 | 11.1 | 7.0 | 53.3 | 1,780 | 1,261 | 532 |
| 4 | 23,810 | 120.5 | 539 | 9.0 | 6.4 | 49.1 | 2,250 | 1,562 | 345 |
| 5 | 29,121 | 134.3 | 740 | 7.7 | 5.8 | 48.0 | 2,510 | 1,435 | 102 |
| Before 1976 thinning: | | | | | | | | | |
| 1 | 8,730 | 56.3 | 96 | 21.3 | 10.4 | 62.7 | 1,222 | 1,164 | 3,654 |
| 2 | 15,207 | 86.1 | 215 | 14.2 | 8.6 | 56.6 | 1,870 | 1,716 | 2,366 |
| 3 | 21,716 | 114.8 | 354 | 11.1 | 7.7 | 58.2 | 2,471 | 2,173 | 1,464 |
| 4 | 29,244 | 143.9 | 534 | 9.0 | 7.0 | 55.5 | 3,103 | 2,584 | 1,168 |
| 5 | 33,917 | 155.7 | 734 | 7.7 | 6.2 | 53.6 | 3,317 | 2,445 | 706 |
| After 1976 thinning: | | | | | | | | | |
| 1 | 5,078 | 34.2 | 51 | 29.2 | 11.1 | -- | 760 | 731 | 2,876 |
| 2 | 10,006 | 59.3 | 129 | 18.4 | 9.2 | -- | 1,301 | 1,216 | 2,368 |
| 3 | 15,012 | 82.7 | 225 | 13.9 | 8.2 | -- | 1,808 | 1,627 | 1,464 |
| 4 | 20,029 | 104.0 | 333 | 11.4 | 7.6 | -- | 2,248 | 1,957 | 1,168 |
| 5 | 24,779 | 121.0 | 464 | 9.7 | 6.9 | -- | 2,621 | 2,138 | 706 |

1/ Average height of trees measured with dendrometer (about 15 per plot).

2/ Total cubic-foot volume--entire stem, inside bark, all trees.
Merchantable cubic-foot volume--trees 5.0-inch d.b.h. and larger to a 4-inch top d.i.b.
Board-foot volume--International 1/4-inch rule, trees 10.0-inch d.b.h. and larger to a 6-inch top d.i.b.

25,000 square feet of bole area per acre.[2/] Corresponding stand densities in terms of basal area are also given (table 1). The two plots assigned to each density level were thinned to the same bole area level in 1966 and 1976.

In general, plots were thinned from below to leave the required number of the largest and most vigorous trees as evenly spaced as possible (fig. 1). None of the slash from the thinnings was removed from the plots.

Diameters of all plot trees were measured to the nearest 0.1 inch after the 1965, 1970, and 1975 growing seasons. On each plot, about 15 trees,

[2/] Bole area is a close approximation of the cambial area of the main stem. See Lexen (1943) and Smith (1962, p. 102) for a discussion of the advantages of bole area as a measure of stand density.

*Figure 1.--One of the 10,000-square-foot bole area density plots after initial thinning in 1966, with an average spacing of 14 feet. Basal area is about 50 square feet per acre.*

proportionately distributed over the range of diameters, were measured with an optical dendrometer in 1966, 1970, and 1975. The measurements were used to calculate an equation expressing volume and bole area of the entire stem inside bark as a function of diameter. The same trees were measured each time. New equations were calculated after each measurement and used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the two 5-year growth periods. Height growth was measured by dendrometer on trees chosen for volume equation measurements.

Split-plot analyses of variance were used to test significance of treatment effects; and nonlinear regression analyses related diameter, basal area, and volume growth to residual bole area and basal area.

## Results

### *DIAMETER GROWTH*

Diameter growth was greatest on the most heavily thinned plots during

both 5-year study periods (table 2). The average growth during the first period declined from 0.36 inch per year at the lowest density level to 0.11 inch per year at the highest density partly because of a larger number of smaller, slower growing trees in the high density plots. During the second period, the diameter growth rate at the lowest density (0.32 inch per year) was four times the growth at the highest density (0.08 inch per year). These differences in diameter growth rate between growing-stock levels were significant ($P < 0.01$).

Diameter growth decreased from the first to the second period at each density level. This difference in growth rate between the two periods was significant ($P < 0.01$) and ranged from 11 percent at the lowest stocking level to 27 percent at the highest. No significant interaction existed between growth periods and growing-stock levels.

A highly significant curvilinear relationship existed between periodic annual diameter increment and stand bole area or basal area at the beginning of each growth period (figs. 2 and 3). Bole area and basal area each explained about 98 percent of the variation in diameter growth between plots during both periods.

During the 10 years of this study, the average stand diameter increased by 6.2 inches in the lowest density plots compared with a 2.8-inch increase in the highest density plots. Tree growth made up about one-third to three-quarters of the diameter increase, and the two thinnings resulted in the additional change (table 3). As a result of removal of smaller trees and faster growth on the residual trees in the lowest density plots, the average diameter in these plots was 61 percent greater in 1976 than in the highest density plots (11.1 vs 6.9 inches) (table 1). Diameter growth of larch and lodgepole pine was similar during both periods.

Diameter growth of the 75 largest trees per acre decreased significantly with increasing stand density in the same manner as growth of all trees (table 2). During the 10-year period, these largest trees grew almost 2 inches more in diameter at the lowest than at the highest density level.

Table [illegible] per acre of [illegible] and [illegible] by initial [illegible] at age 33

| [illegible] level | Residual density | | Diameter growth[1] | All trees: Basal area growth | | | Total volume growth | | | Merchantable volume growth including ingrowth | | | Board-foot ingrowth | | 75 largest trees: Diameter growth[1] | Gross total volume growth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trees | Basal area | | Net | Mortality | Gross | Net | Mortality | Gross | Net | Mortality | Gross | Board feet | Percent | Inches | Cubic feet |
| | Square feet | | Inches | Square feet | | | Cubic feet | | | Board feet | | | | | | |
| Age 33-38 | | | | | | | | | | | | | | | | |
| 1 | [illegible] | [illegible] | 0.36 | [illegible] | | 2.86 | 64 | -- | 64 | 180 | -- | [illegible] | 170 | 94.4 | 0.36 | 54 |
| 2 | [illegible] | [illegible] | 3.72 | [illegible] | | 3.72 | [illegible] | -- | 86 | 59 | -- | 59 | 59 | 100.0 | 0.27 | 40 |
| 3 | [illegible] | [illegible] | 0.18 | [illegible] | .03 | [illegible] | [illegible] | 1 | [illegible] | [illegible] | -- | 68 | 43 | 63.2 | 0.24 | 31 |
| 4 | 19,300 | 96.0 | [illegible] | 4.82 | [illegible] | [illegible] | [illegible] | 4 | 131 | 69 | -- | 69 | 69 | 100.0 | 0.22 | 30 |
| | 24,200 | 110.0 | [illegible] | 4.90 | .17 | [illegible] | [illegible] | 3 | 136 | [illegible] | -- | [illegible] | [illegible] | 100.0 | 0.19 | 26 |
| [illegible] | | | | | | | | | | | | | | | | |
| | [illegible] | [illegible] | 0.32 | [illegible] | -- | 3.20 | [illegible] | -- | 85 | 541 | -- | 541 | 403 | 74.5 | 0.33 | 73 |
| | 12,100 | 68.0 | [illegible] | 3.58 | - | 3.58 | [illegible] | -- | 107 | 414 | -- | 414 | 374 | 90.5 | 0.20 | 48 |
| | 17,800 | 93.0 | [illegible] | [illegible] | - | [illegible] | 138 | -- | 138 | 186 | -- | 186 | 130 | 70.2 | 0.18 | 48 |
| | 23,800 | 120.0 | [illegible] | [illegible] | .16 | 4.85 | [illegible] | -- | 173 | 164 | -- | 164 | 125 | 76.2 | 0.16 | 44 |
| | 29,100 | 134.0 | 0.08 | 4.29 | .11 | [illegible] | [illegible] | -- | 163 | 120 | -- | 120 | 96 | 80.0 | 0.14 | 36 |

[illegible] [illegible] trees [illegible] through [illegible]-year period.

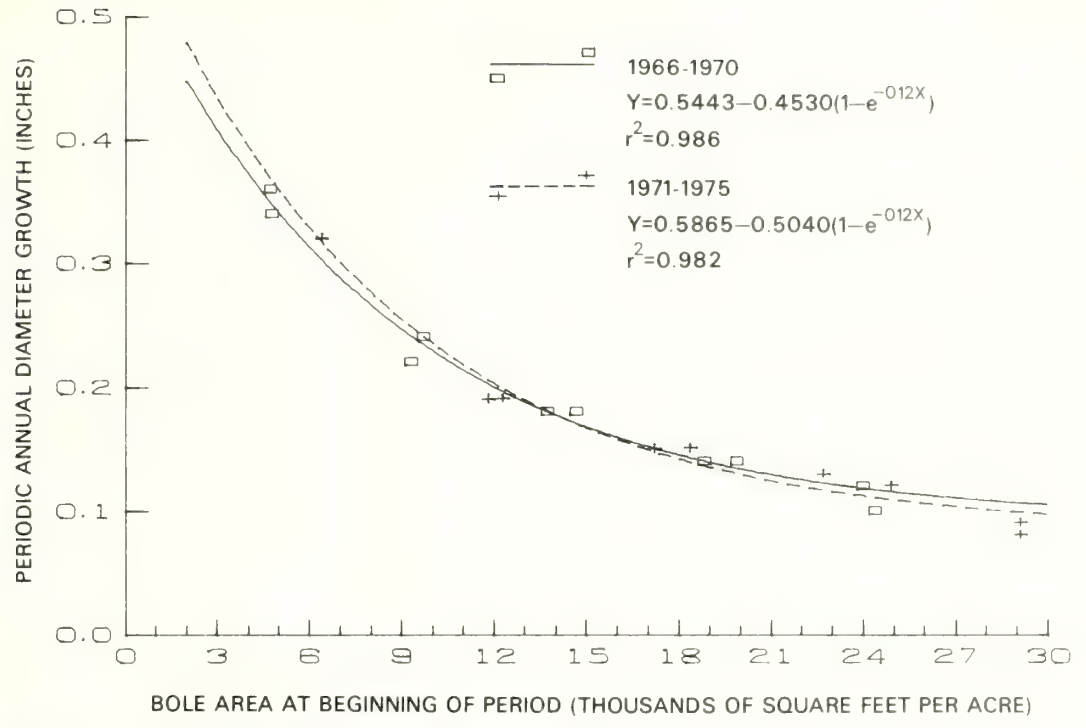


*Figure 2.--Periodic annual diameter increment by density level (bole area) and growth period.*

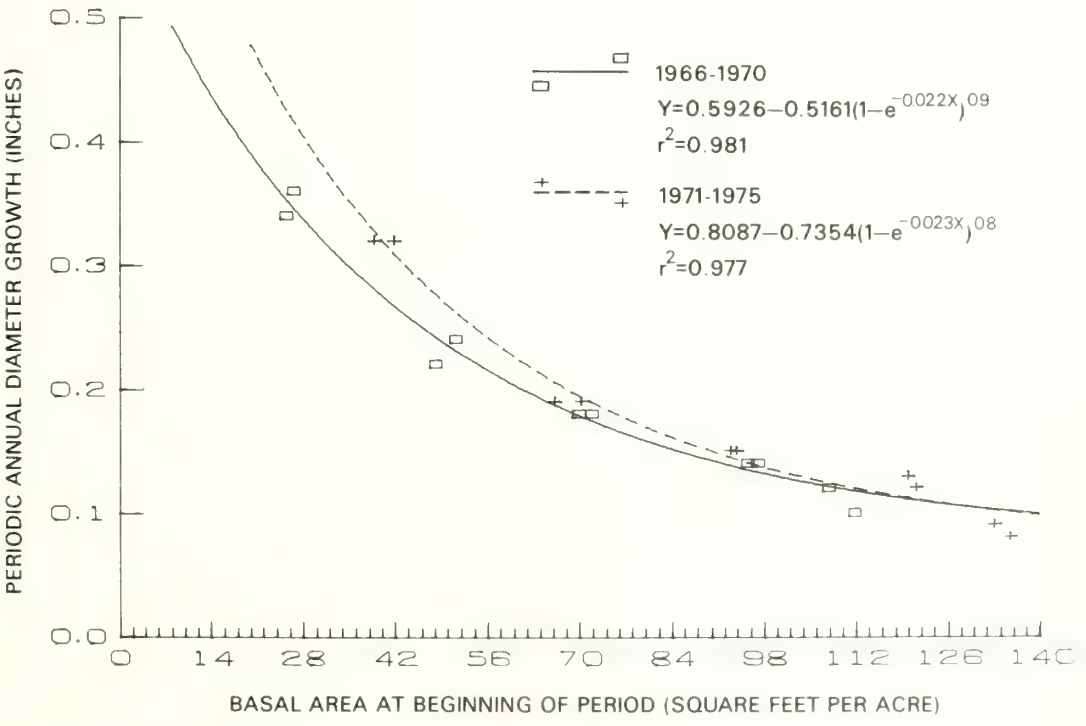


*Figure 3.--Periodic annual diameter increment by density level (basal area) and growth period.*

Table 3--*Increase in quadratic mean stand diameter from 1966 to 1976 as a result of growth and two thinnings*

| Period and bole area level | Increase in average diameter | Increase attributed to: | | |
|---|---|---|---|---|
| | | Thinning | Growth | |
| (M ft$^2$ per acre) | Inches | Inches | Inches | Percent |
| 1966-70 | | | | |
| 5 | +3.9 | +2.1 | +1.8 | 46 |
| 10 | +3.0 | +1.9 | +1.1 | 37 |
| 15 | +2.7 | +1.8 | +0.9 | 33 |
| 20 | +2.0 | +1.3 | +0.7 | 35 |
| 25 | +1.7 | +1.1 | +0.6 | 35 |
| 1971-76 | | | | |
| 5 | +2.3 | +0.7 | +1.6 | 70 |
| 10 | +1.6 | +0.6 | +1.0 | 63 |
| 15 | +1.2 | +0.5 | +0.7 | 58 |
| 20 | +1.2 | +0.6 | +0.6 | 50 |
| 25 | +1.1 | +0.7 | +0.4 | 36 |
| 1966-76 | | | | |
| 5 | +6.2 | +2.8 | +3.4 | 55 |
| 10 | +4.6 | +2.5 | +2.1 | 46 |
| 15 | +3.9 | +2.3 | +1.6 | 41 |
| 20 | +3.2 | +1.9 | +1.3 | 41 |
| 25 | +2.8 | +1.8 | +1.0 | 36 |

Another way to look at diameter growth is to consider growth of individual trees rather than average plot increment. Although, in general, larger trees grew faster than smaller trees, there was only a weak relationship between initial diameter and diameter growth for each period. Regressions of diameter growth on diameter by plot resulted in $r^2$ values ranging from 0.002 to 0.53 with the best relationship found on high density plots because of a greater range of diameters.

## *HEIGHT GROWTH*

Height growth varied little in response to changes in stand density during both growth periods (fig. 4). Only small differences in growth occurred at the various bole area levels, and there was no indication of any correlation between height growth and stand density. No significant differences were found among density levels and growth periods, and the level-period interaction was not significant. Average increment ranged from 1.0 to 1.4 feet annually and growth of individual trees ranged from 0 to 2.8 feet per year. Larch and lodgepole pine both showed similar rates of height growth during both periods.

## *MORTALITY*

Mortality during the 10 years of this study was negligible. Only 12 of the 1,567 study trees died during the first period and 7 died during the second. All mortality occurred in the two highest density levels except for one tree that died in one of the middle density plots. There was no evidence of larch casebearer (*Coleophora laricella* Hbn.) infestation in any of the plots.

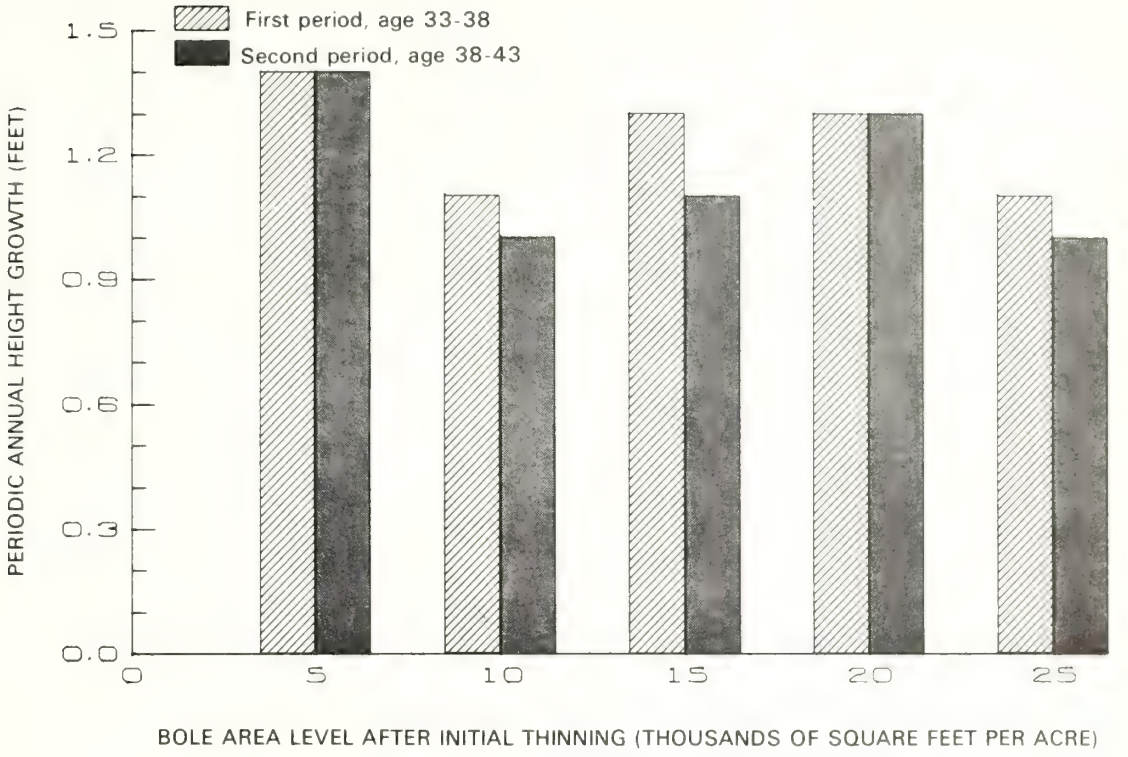


*Figure 4.--Periodic annual height increment by density level (bole area) and growth period.*

## *BASAL AREA GROWTH*

Basal area increment increased during both periods with increasing stand density (table 2). Differences among density levels were significant ($P < 0.01$). Growth slowed only slightly from the first to second period, but the difference was significant ($P < 0.01$). The interaction between density and growth period was also significant ($P < 0.01$) because of the increase in growth at the lowest density level from the first to second period in contrast to a decrease at the other four levels.

The regressions of basal area increment on bole area and basal area did not depart significantly from linearity within the range of the data (figs. 5 & 6). A curvilinear equation forcing the curve through the origin was selected, however, since increment must be zero at zero stand density. The curves through the origin accounted for about the same amount of variation as those limited to the data range. Bole area and basal area were about equal as predictors of basal area increment.

## *VOLUME GROWTH*

Total gross cubic volume increment was excellent during the 10-year study period, reaching a high of 173 $ft^3$ per acre annually (table 2). Volume growth increased with rising growing stock level during both periods, and the difference among density levels was significant ($P < 0.01$). Gross cubic

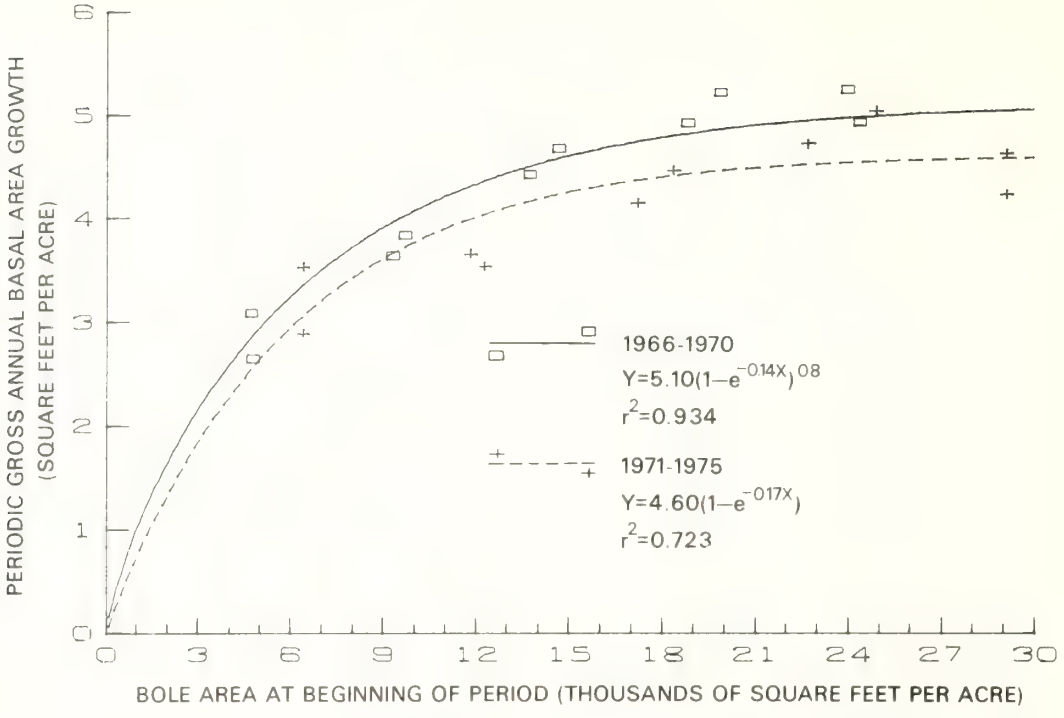


*Figure 5.--Periodic gross annual basal area increment by density level (bole area) and growth period.*

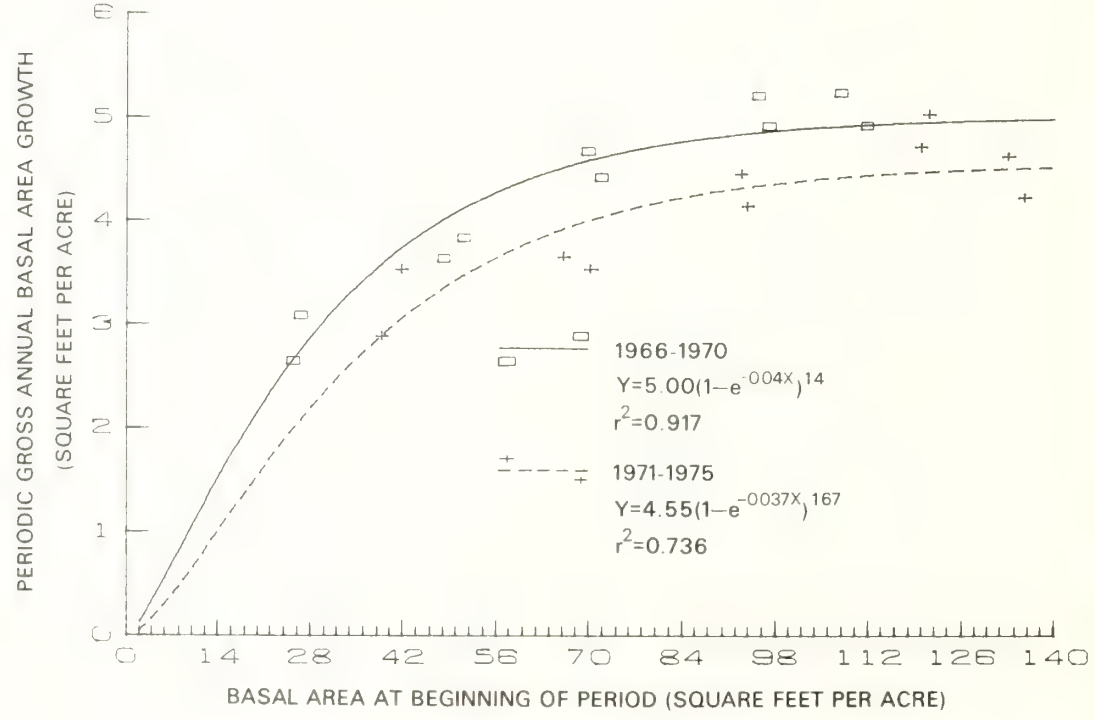


*Figure 6.--Periodic gross annual basal area increment by density level (basal area) and growth period.*

increment increased significantly ($P < 0.01$) from the first to second period. This difference in growth between the two periods ranged from 20 to 34 percent. No significant interaction was found between growth periods and density levels. Net volume growth was essentially the same as gross because of the small amount of mortality during the study period.

Volume increment was about twice as great on the highest as on the lowest density plots during both periods; but much of this growth at high densities is distributed on a large number of smaller, slower-growing trees. In contrast, concentration of growth on fewer faster growing trees in the heavily thinned plots resulted in 96 trees per acre producing about 50 percent of the cubic volume grown by 745 trees per acre.

The regressions of volume increment on bole area (fig. 7) and on basal area (fig. 8) are similar in terms of the amount of explained variation--accounting for about 84 to 92 percent of the variation in volume increment. Similar to basal area growth, the cubic volume regressions were linear within the range of the data but were forced through zero with only a small reduction in $r^2$ values. Although these regressions show increased growth with rising stand density, increment was only slightly more at the highest density than at the second highest level during the first period and decreased somewhat during the second period (table 2). This suggests that full site utilization occurs as stand density approaches 25,000 $ft^2$ of bole area per acre and that increasing stocking beyond this level may not result in an increase in total volume increment.

During the 10-year study period, gross volume growth of the 75 largest trees per acre responded to stand density

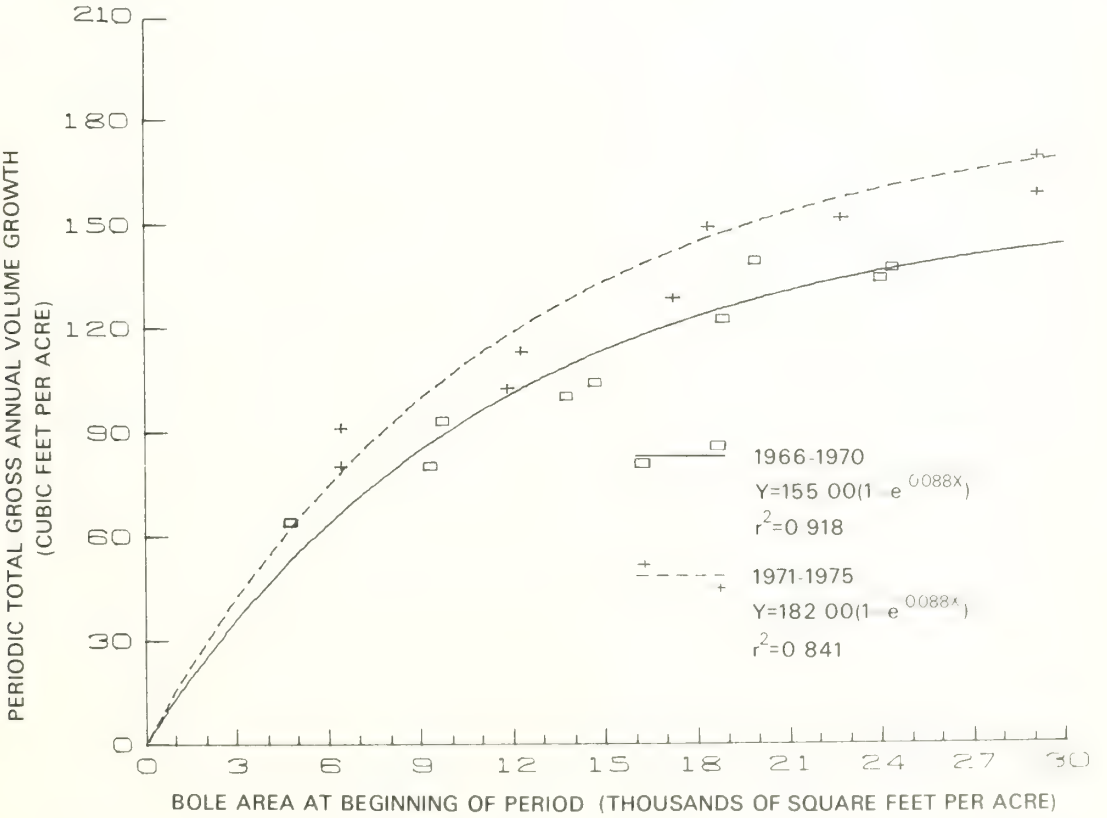


*Figure 7.--Periodic total gross annual cubic volume increment by density level (bole area) and growth period.*

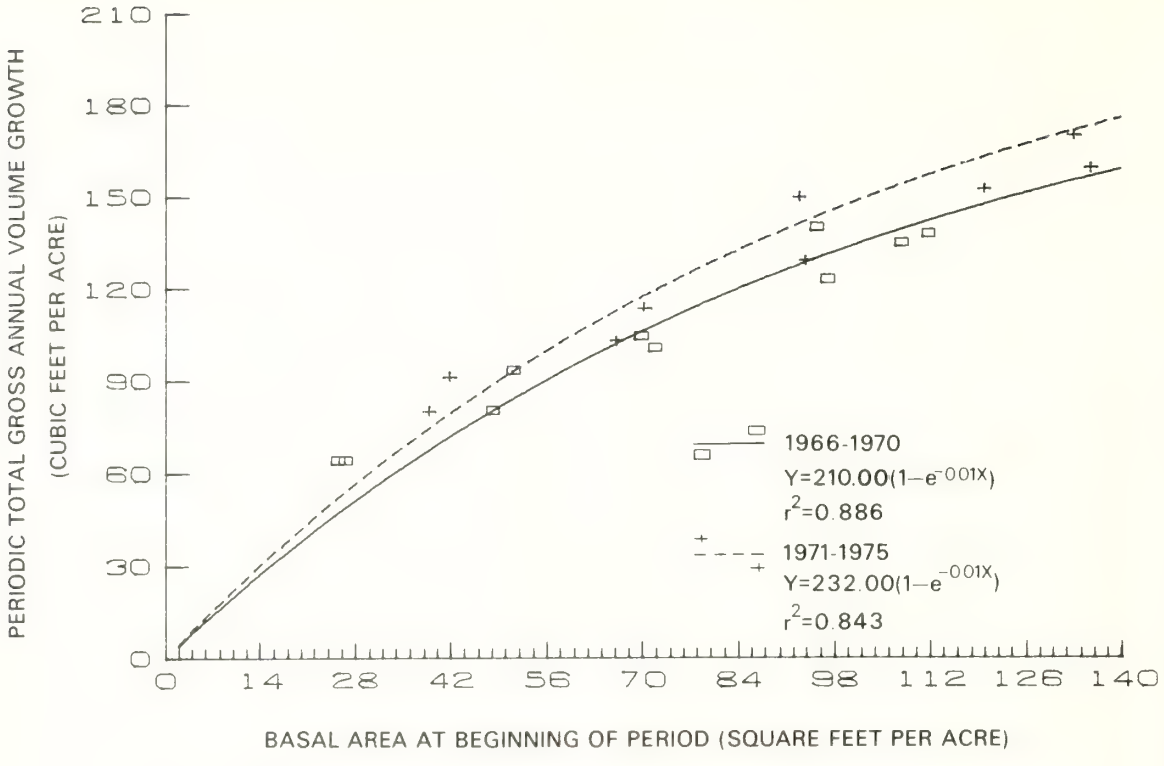


*Figure 8.--Periodic total gross annual cubic volume increment by density level (basal area) and growth period.*

in the same manner as diameter growth--with greatest growth at the lowest density level (table 2). About twice as much wood has been added to these larger trees at the lowest density level than at the highest. This clearly illustrates the effect of thinning in transferring growth to the larger trees more rapidly in the low density plots.

Board-foot volume increment increased substantially during the second period as compared to the first period; but in young stands such as these, ingrowth still accounts for the largest portion of the board-foot increment (75 to 90 percent during the second period) (table 2). Because of the large variation between plots due to ingrowth, board-foot growth data were not subjected to statistical analyses. It is apparent, however, that board-foot increment was considerably greater at the lowest stocking level and decreased with increasing stand density because of the more rapid diameter growth in low density plots moving more trees into the sawlog class (ingrowth). Board-foot growth in the high density plots should increase rapidly in the future because of the many trees now in or approaching merchantable size classes. No mortality of trees 10.0-inch d.b.h. or larger occurred during either growth period so gross and net board-foot growth are equal.

As might be expected in pole stands, mean annual increment is still increasing at all density levels (table 4). Cubic volume

Table 4--*Net mean annual increment per acre*

| Bole area level | Age | | |
|---|---|---|---|
| | 33 | 38 | 43 |
| ($M\ ft^2$ per acre) | | Cubic feet | |
| 5 | 60 | 61 | 64 |
| 10 | 69 | 72 | 76 |
| 15 | 72 | 76 | 83 |
| 20 | 70 | 78 | 89 |
| 25 | 67 | 75 | 85 |

yields measured on these plots are similar to yield table data for larch in Montana (Schmidt et al. 1976). If this similarity continues, culmination of mean annual increment will occur at about 60 to 70 years of age.

## *BOLE AREA-BASAL AREA RELATIONSHIPS*

Bole area was selected as the measure of stand density in this study since a given bole area was thought to represent a more or less constant level of competition over time in contrast to basal area which, for a given level of competition, increases with age and average diameter. Therefore, it was expected that maintaining a constant bole area level by thinning as the stand grows older should result in a rising level of basal area; this occurred during the 10 years of observation of the present study. Because of the more rapid rate of change of basal area relative to bole area, basal area increased with stand age for any given bole area level (fig. 9). For example,

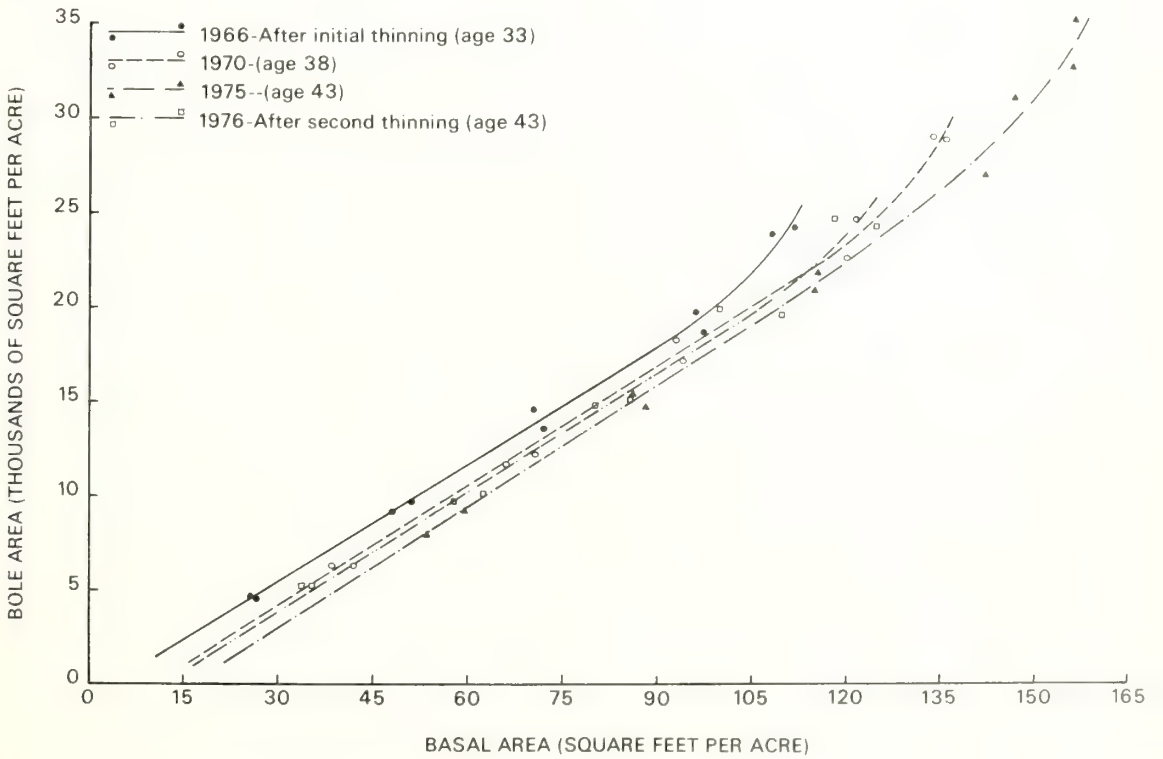


*Figure 9.--Relationship of bole area to basal area.*

in 1966 at age 33, a basal area density of about 51 $ft^2$ per acre was equivalent to a bole area density of 10,000 $ft^2$ per acre. After the second thinning in 1976 reduced bole area levels to their initial values, the degree of competition indicated by the 10,000 $ft^2$ per acre bole area level was now equal to about 60 $ft^2$ per acre of basal area; an increase of about 9 $ft^2$ per acre over the basal area value after the initial thinning.

Although bole area appears to be a more stable measure of stand density than basal area, it is not well suited for routine use in the field because it is a function of diameter, height, and stem taper. For foresters interested in using bole area in thinning prescriptions, I have expressed bole area in terms of more easily used measures--basal area and number of trees by various stand diameters (table 5). For example, in order to maintain a bole area density of 15,000 $ft^2$ per acre, basal area should rise from 36 to 99 $ft^2$ per acre as average stand diameter increases from 2 to 10 inches.

I want to emphasize that the bole area-basal area relationships given here were derived from data obtained in high-site larch plots and are not intended to be representative over the entire range of site classes. Also, these data should not be extrapolated to larger diameter classes because of changing diameter, height, and form relationships which are likely to occur. Finally, the data shown in table 5 are not to be considered as a thinning schedule or recommended stocking level guide. They are only an estimate of the basal area or number of trees needed per acre to maintain a more or less constant bole area level over time for a limited range of diameter classes.

## Discussion

It is evident from the 10-year growth data that thinning has effectively concentrated growth on a small number of crop trees in the low density plots. The volume growth rate of the 75 largest trees per acre at the lowest stocking level was about twice as great as an equal number of largest trees at

Table 5--[illegible] 1/

| Average stand diameter | Bole area--thousands of square feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | | 10 | | 15 | | 20 | | 25 | |
| | Number of trees | Basal area | Number of trees | Basal area | Number of trees | Basal area | Number of trees | Basal area | Number of trees | Basal area |
| Inches | | Sq. ft. | | Sq. ft. | | Sq. ft. | | Sq. ft. | | Sq. ft. |
| 2 | 556 | 12 | 1,111 | 24 | 1,667 | 36 | 2,222 | 48 | 2,778 | 61 |
| 4 | 205 | 18 | 410 | 36 | 615 | 54 | 820 | 72 | 1,025 | 89 |
| 6 | 119 | 23 | 238 | 47 | 357 | 70 | 476 | 93 | 595 | 117 |
| 8 | 81 | 28 | 162 | 57 | 244 | 85 | 325 | 113 | 406 | 142 |
| 10 | 60 | 33 | 121 | 66 | 181 | 99 | 242 | 132 | 302 | 165 |
| 12 | 47 | 37 | 95 | 74 | 142 | 112 | 190 | 149 | 237 | 186 |
| 14 | 39 | 41 | 77 | 82 | 116 | 124 | 154 | 165 | 193 | 206 |
| 16 | 32 | 45 | 65 | 90 | 97 | 135 | 129 | 180 | 161 | 225 |

1/ Limits of basic plot data enclosed within solid line. Values in table were derived as follows: (1) the bole area equations expressing bole area as a function of diameter in 1966, 1970, and 1975 were used to calculate three bole area values per tree for each of the diameter classes, (2) a mean bole area per tree for each diameter class was found, (3) the mean bole area per tree for each diameter class was divided into each bole area level to obtain the number of trees per acre for that diameter class, and (4) basal area per tree for each diameter class was multiplied by trees per acre to obtain basal area per acre.

the highest density level. And the average diameter of trees in the low density plots was 11.1 inches in 1976, an increase of 4.2 inches over the average diameter found in the high density plots.

Because of the linear trend of volume increment on stand density, each reduction in growing stock resulted in a decrease in volume growth. Therefore, if markets for small trees exist and frequent commercial thinnings are possible to utilize mortality, a high residual stand density is indicated to more fully utilize the productive capacity of the site and maximize wood production. If, on the other hand, no pulpwood market exists and the management objective is to increase water and forage yields, precommercial thinning is necessary to eliminate the overstocked conditions existing in many natural larch stands.

Obviously, decisions concerning stocking levels after precommercial thinning should consider not only timber management objectives but also the relative importance of other forest resources to the land manager. The primary timber management objective of precommercial thinning is to stimulate diameter growth rate of residual trees so merchantable products may be harvested sooner. Thus, the stocking level left after precommercial thinning depends upon the land manager's estimate of the minimum size tree (d.b.h.) that will be merchantable in the future. By leaving a high stand density level after precommercial thinning, a forester is assuming that smaller trees will support a commercial thinning in the future; and conversely, a low residual stand density implies that larger trees are needed for a commercial thinning.

In a shade intolerant species such as western larch, early thinning should have a high priority. Competition in young, overstocked larch stands results in crown reduction with subsequent decreases in diameter and height growth. In addition, small, low-vigor trees are not as resistant to damage from wind, snow, insects, and diseases as trees having adequate growing space. Studies in Montana by Schmidt (1966) and in Holland by Dik (1975) suggest that the ideal time for precommercial thinning occurs when trees are about 10 years old and from 10 to 15 feet tall. This is similar to the time of thinning recommendations for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) given by Reukema (1975).

Although the greatest benefits from precommercial thinning occur in young 10- to 15-year-old stands before crowns begin to shorten, considerable gains are still possible from precommercial thinning, as demonstrated in this study, in larch stands up to 30 years of age and 45 feet tall. The younger stands, however, should be given preference for precommercial thinning.

The major conclusions reached after 10 years of growth are:

1. Growth response to stocking level control resulted in less total cubic volume increment per acre but greater diameter and volume growth of individual trees as stand density decreased.

2. Precommercial thinning in these young pole stands concentrated growth on crop trees thus shortening the time until a commercial thinning is possible.

3. Losses from mortality were not a problem in the plots thinned from below even at the highest density level.

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Seidel, K. W.
1977. Levels-of-growing-stock study in thinned western larch pole stands in eastern Oregon. USDA For. Serv. Res. Pap. PNW-221, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

The 10-year growth response from a levels-of-growing-stock study in an even-aged western larch stand in eastern Oregon, first thinned at age 33, showed that trees growing at lower stand densities grew more rapidly in diameter but did not grow faster in height than trees in high density plots. Both basal area and total cubic volume increment increased as stand density increased. Despite the large reduction in volume increment at the lower densities, most of the wood, however, is concentrated on a fewer number of faster growing trees that can reach usable size sooner.

KEYWORDS: Growing stock (-increment/yield, thinnings (-stand volume, stand density, forest improvement cutting, stand improvement, increment (diameter), increment (basal area), increment (stand volume), western larch, Oregon (eastern).

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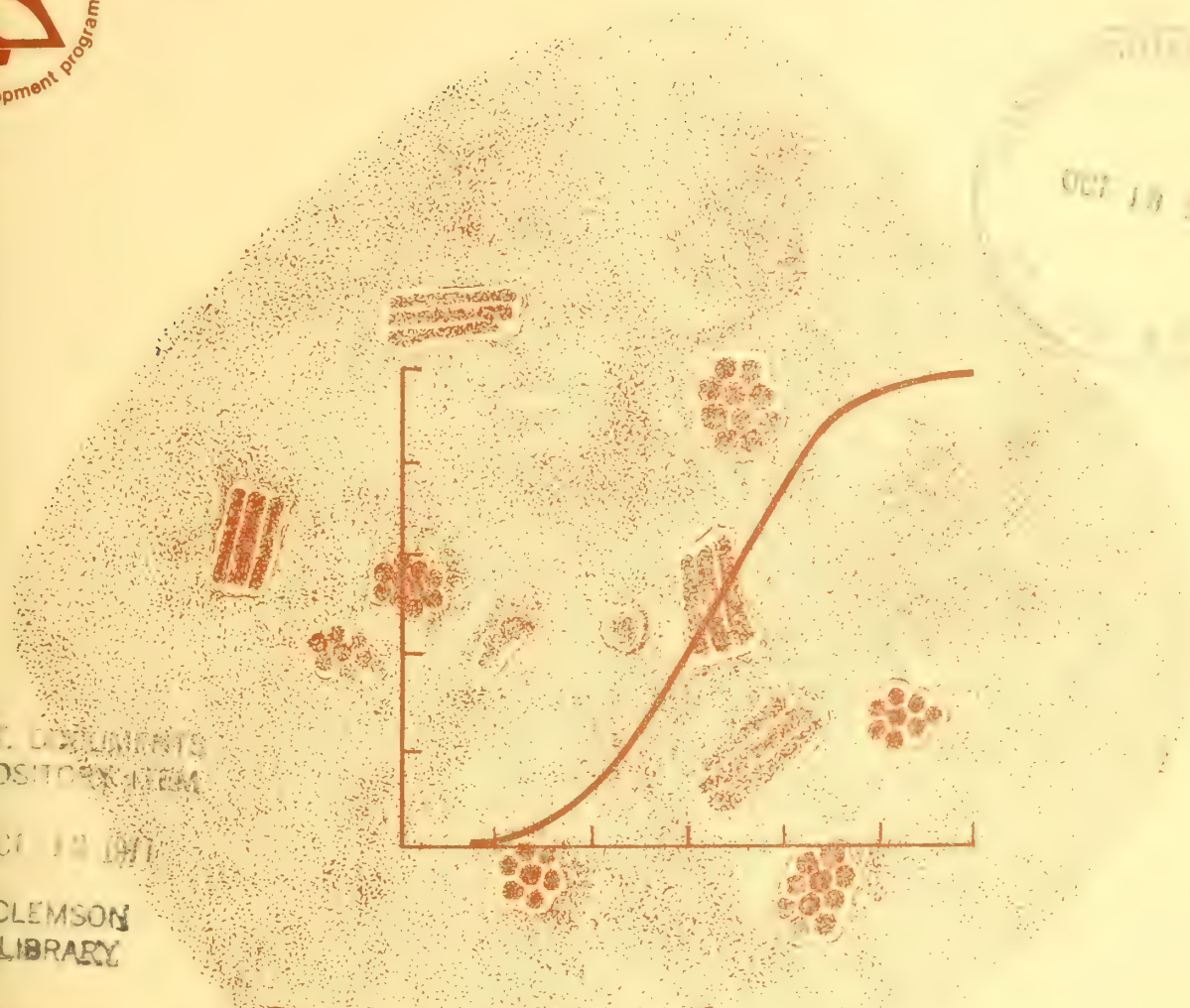
USDA FOREST SERVICE RESEARCH PAPER PNW-222
1977



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# Peroral Bioassay of Technical-Grade Preparations of the Douglas-Fir Tussock Moth Nucleopolyhedrosis Virus (*Baculovirus*)

Mauro E. Martignoni
Paul J. Iwai

UBLISHED IN COOPERATION WITH THE
SD DOUGLAS-FIR TUSSOCK MOTH
ROGRAM

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

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We are especially grateful to Henry G. Lasher for his excellent care of the insect stocks. The research reported here was financed in part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

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# *PERORAL BIOASSAY OF TECHNICAL-GRADE PREPARATIONS OF THE DOUGLAS-FIR TUSSOCK MOTH NUCLEOPOLYHEDROSIS VIRUS* (BACULOVIRUS)

*Reference Abstract*

Martignoni, Mauro E., and Paul J. Iwai.
1977. Peroral bioassay of technical-grade preparations of the Douglas-fir tussock moth nucleopolyhedrosis virus (*Baculovirus*). USDA For. Serv. Res. Pap. PNW-222, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The potency of industrial preparations of viruses for control of injurious insects can be estimated reliably only by means of biological assay. We describe a simple, yet sensitive peroral bioassay procedure for technical-grade preparations of nucleopolyhedrosis virus. This procedure has been accepted by the Forest Service and the U.S. Environmental Protection Agency as the standard method for assaying industrial virus preparations for control of the Douglas-fir tussock moth.

KEYWORDS: Bioassay, nucleopolyhedrosis, virus (insect), virus (-insecta, virus (-forest pest control, insect diseases, diseases (insect), insect damage control (forest), biological control (-forest pests, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

## *RESEARCH SUMMARY*

*Research Paper PNW-222*

*1977*

Gravimetric, chemical, and particle-counting procedures are available for estimating the approximate activity of preparations of insect viruses. Only by biological assay, however, can the actual potency (activity or infectivity titer) of such preparations be determined. To minimize variation and to increase the reproducibility of potency assessments, we describe a procedure designed to cope specifically with the usual complexity of measuring a biological stimulus (nucleopolyhedrosis virus) in a living host (Douglas-fir tussock moth). This bioassay, several years in development, has been tested repeatedly in its present format. It has a high degree of reproducibility. The final protocol, as presented here, has been accepted by the U. S. Environmental Protection Agency and by the Forest Service as part of the production control procedure for industrial preparations of nucleopolyhedrosis virus of the Douglas-fir tussock moth.

## Introduction

Finney (1971) defines bioassay as follows: "In its widest sense, the term means the measurement of the potency of any stimulus, physical, chemical or biological, physiological or psychological, by means of the reactions that it produces in living matter." Although the biological method of measuring stimuli is usually cumbersome and time-consuming, it is adopted as a rule when a physical or chemical measure of the stimulus does not provide reliable information on its biological activity. This is especially true for technical-grade preparations, when a physical or chemical measure of the active ingredient can be difficult, if not impossible, to obtain.

Biological assay, because of its exacting requirements and technical complexity, appears to have been shunned by most workers as a method for quantifying technical nucleopolyhedrosis virus preparations for field use. A study of the literature shows that the number of polyhedral inclusion bodies (PIB) per unit weight or volume of nucleopolyhedrosis virus preparations, or per unit treated area, is the most commonly used "measure" of the potency of such preparations. In the United States, for instance, nucleopolyhedrosis virus preparations of *Heliothis* sp. on cotton are measured in *viral units* (1 VU = $10^9$ PIB) and in *larval equivalents* (1 LE = 6 x $10^9$ PIB = 6 VU) (Allen 1967; Woodall and Ditman 1967; Pinnock 1975). PIB counts of technical preparations, by microscopic as well as electronic procedures, can be quite inaccurate, however. Variations in counts among operators and among laboratories are large (Martignoni and Iwai 1968; C. M. Ignoffo, *quoted in* Burges and Thomson 1971). Furthermore, because of the considerable variation in methods of storage of technical nucleopolyhedrosis virus preparations (packaging, moisture, temperature, age), PIB counts cannot be translated reproducibly into units of activity of these preparations. Not surprisingly, dose computations based on PIB counts have been eyed with suspicion for some time. Pinnock (1975) states: "Probably the greatest imprecision in the reporting of virus trials for crop protection occurs in the estimation of the dosage of virus applied. Larval equivalents (LE) are the most frequently used measure of dose, yet the measure is highly variable,. . . ." After a statistical study of PIB counts obtained by electronic transducer and through conventional microscope counting procedures, we concluded ". . . that the polyhedron counts of suspensions prepared with raw tissue homogenates are unreliable, and that the biological assay of such suspensions provides a more consistent estimate of the potency of such preparations (e.g., $LD_{50}$ in nanograms of preparation per gram of larval weight)" (Martignoni and Iwai 1968). Yearian (1975) pleads for standardization of the activity of *Baculovirus* preparations used in the field. Finally, and unequivocally, the U.S. Environmental Protection Agency (1975) requires that quantitation of nucleopolyhedrosis and granulosis virus preparations be based on bioassays rather than counts of inclusion bodies.

## History

During the late sixties and the seventies, the U.S. Forest Service and private industry developed a strong interest in nucleopolyhedrosis virus preparations for the control of the Douglas-fir tussock moth, *Orygia pseudotsugata*. Pilot-plant production methods, laboratory testing procedures, and field application techniques were developed and tried. The development and testing of biological

assay procedures was part of this broad effort to manage an economically important insect pest by means of a viral product.

In 1966, the first pilot-plant scale batches of a technical nucleopolyhedrosis virus preparation were produced for the Forest Service by industry. Samples of these batches were assayed in our laboratory by a microfeeding technique, which permits individual inoculation of larvae with glass microcatheters. We used 75±5-mg larvae. The rearing temperature was $30^{\circ}\pm0.5^{\circ}C$, and the holding period was 12 days. The dose unit was nanograms (dry weight) of sample; the $LD_{50}$ was expressed in nanograms per larva. The details of the procedure were described for the first time in 1967, and they remained essentially unchanged through several revised editions of the pamphlet (Martignoni 1975). The potency of each batch of technical nucleopolyhedrosis virus preparation produced since 1966 was measured in our laboratory by the microfeeding bioassay technique. In 1974, we submitted this procedure to the Registration Division of the U.S. Environmental Protection Agency, as part of the U.S. Forest Service application for a temporary permit for experimental use of the nucleopolyhedrosis virus preparation in Pacific Northwest forests (EPA Temporary Permit No. 27586-EXP-2G, June 4, 1974).

The intense interest of the Forest Service and of private companies in viral preparations for the control of Douglas-fir tussock moth outbreaks will lead, eventually, to industrial-scale production of virus and to routine bioassay by the industry and its customers. Because the microfeeding technique requires certain instruments and technical skills available only in few research laboratories, we decided to develop an alternate bioassay procedure. This new procedure should be simple, yet sensitive; it should not require specialized instrumentation other than that available in most biological laboratories.

During 1974 and 1975, we developed and tested a "diet-surface treatment" (DST) bioassay procedure similar in principle to that used by Ignoffo (1966) for the bioassay of the nucleopolyhedrosis virus of *Heliothis zea*. In a DST procedure, the viral preparation is placed directly on the surface of the diet, in an appropriate rearing container, rather than being blended with the diet. Procedures in which the active agent is blended with the diet (e.g., the bioassay of *Bacillus thuringiensis* δ-endotoxin; Dulmage et al. 1976) are known as "diet-incorporation" techniques. The major difference between the *Heliothis* DST procedure and ours is the age of the test larvae. We use recently molted, second-instar *O. pseudotsugata* larvae. Ignoffo's procedure prescribes neonate *H. zea* larvae. We use second-instar larvae, because neonate larvae of *O. pseudotsugata* are too delicate. Their survival rate to second instar, on an artificial diet, is usually less than 80 percent, and it can be as low as 60 percent. The causes of this high mortality rate are unknown. No cases of nucleopolyhedrosis have been observed in our bioassay strain. In contrast, the survival rate of second-instar larvae to the third instar, on artificial diet, is usually 100 percent and rarely lower than 95 percent.

The DST bioassay procedure described here was submitted to the Registration Division of the U.S. Environmental Protection Agency, as part of the General Product Chemistry section of the Forest Service application for registration of "TM BioControl-1," the nucleopolyhedrosis virus of the Douglas-fir tussock moth (EPA Registration No. 27586-1, August 11, 1976). Currently,

this bioassay procedure is the official method for testing the activity of nucleopolyhedrosis virus preparations for the control of the Douglas-fir tussock moth. Because of the assay's sensitivity, it is also suitable for environmental monitoring programs and for susceptibility studies in populations of *O. pseudotsugata*.

A method for the standardization of the potency of technical-grade nucleopolyhedrosis virus preparations has been submitted to the U.S. Environmental Protection Agency. We will present the details of the method, its reproducibility, and its sensitivity in a future publication.

## Standardized Bioassay

I. PREPARATION OF THE TEST CUPS

A. Materials and equipment

1. A supply of mixed, warm liquid diet 65-W-PEN (Thompson and Peterson[1/]); minimum amount: 300 ml (sufficient for 240 cups).
2. 10-ml wide-tip sterile disposable pipets
3. Disposable analyzer cups (2-ml) with write-on wings, as many as required (one per larva) (Scientific Products diSPo® automatic analyzer beakers, B2715).[2/] The cups are exposed for 30 minutes in a UV sterilizer before being used.
4. Sterile paper tissues
5. Aluminum foil
6. Adhesive labels
7. Rubber aspirator, for pipets
8. Thermometer (for 60°C water bath)
9. Hot plate, with water bath (60°C)
10. Sterile hood
11. Ultraviolet sterilizer

Note: The diameter of the analyzer cup at the level of the 1-ml mark is 11.8 mm and the surface area 109.4 $mm^2$.

B. Procedure

1. Place the container with the mixed warm diet in the water bath, at 60°C. Fill one 10-ml pipet with diet. With a sterile paper tissue, wipe the excess diet off the exterior of the pipet tip.
2. Place the tip of the pipet at the level of the 1-ml mark of the analyzer cup, without touching the wall of the cup. Dispense the diet to that mark. Take your time and be precise.
3. Discard all analyzer cups with air bubbles on the surface of the diet or with streaks of diet on the wall.
4. Let the cups air dry under a sterile hood for a minimum of 1 hour. Wrap batches of 20 analyzer cups with aluminum foil, label, and date. Refrigerate at 4°C. Preferably, these cups should be used within 1 week, but they can be stored and used for up to 2 weeks.

Note: For filling larger batches of test cups (600 or more), we recommend an automatic dispensing device.

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[1/] Thompson, Clarence G., and Linda J. Peterson. How to rear the Douglas-fir tussock moth. Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon 97331. [In press].

[2/] The use of trade, firm, or corporation names in this report is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

## II. SELECTION OF SECOND-INSTAR LARVAE

A. Materials
1. Sterile toothpicks
2. Disposable petri dishes, 100- x 15-mm
3. An adequate supply of late first-instar larvae of *O. pseudotsugata*, usually twice the number of larvae needed for the bioassay; *O. pseudotsugata* larvae reach the second instar about 7 days after hatching, at $21^{\circ} \pm 2^{\circ}$C, on diet 65-W-PEN, in plastic petri dishes.

B. Procedure
1. The day before the test: at 4:00 p.m., select and discard all second-instar larvae present in an appropriate batch of stock larvae (6-7 days after hatching). Only first-instar larvae should remain in the rearing containers.
2. The day of the test: at 9:00 a.m., select the required number of second-instar larvae from the batch screened the previous day. The second-instar age of these larvae is 1-17 hours. Place 20 second-instar larvae to a petri dish, without diet.

   Note: A bioassay requires 20 larvae per group and two groups per dose level. Two replicates at five dose levels, with two control groups, require a total of 240 second-instar larvae.

## III. PREPARATION OF THE STOCK VIRUS SUSPENSION

A. Materials and equipment
1. Virus sample (dry powder)
2. Sterile buffered saline, prepared as follows:
   4.266 g BES (N, N-bis [2-hydroxyethyl]-2-aminoethanesulfonic acid);
   9.000 g NaCl;
   0.0075 g DOSS (dioctyl sulfosuccinate, sodium) *or* 100 µl of a 7.5% DOSS solution, such as Laboratory Aerosol® OT, Fisher Scientific Corporation;
   distilled water to 1,000 ml;
   adjust the pH to 7.13, at $20^{\circ}$C, with normal NaOH;
   autoclave (the pH will be 7.15 after autoclaving), *or* sterilize by filtration.
3. Sterile measuring cylinder (50-ml)
4. Sterile 125-ml Erlenmeyer flask, with aluminum foil closure
5. Sterile microspatula
6. Semi-micro Monel® blender vesse
7. Blender base with two-speed motor
8. Analytical balance (readability: at least 0.1 mg)

B. Procedure
1. Weigh 50 mg of virus preparation (dry powder) directly in a sterile 125-ml Erlenmeyer flask.
2. Add 50 ml of sterile buffered salin cover with sterile aluminum foil, and mix well.
3. When the material is completely in suspension, usually within 5 minutes, pour the suspension into a sterile semi-micro Monel blender container.
4. Homogenize at low speed for 1 minute.
5. Pour the suspension in the origina Erlenmeyer flask and cover. Refrigerate immediately.
6. Shake repeatedly before each use.

   Note: This suspension is designated as "stock suspension. *It contains 1 mg of preparation per millilite of suspension.*

## IV. PREPARATION OF SERIAL DILUTIONS OF THE STOCK SUSPENSION

A. Materials
1. Stock virus suspension
2. Sterile buffered saline (see III, A, 2)
3. Disposable sterile pipets (1-ml, 5-ml, and 10-ml)
4. Adhesive labels
5. Sterile 20-ml screw-cap vials

$B_1$. Procedure

This procedure should be used if an approximate estimate of the infectivity titer of the virus preparation is *not* available. This is a preliminary (or range-finding) assay.

1. Prepare five serial dilutions of the stock suspension in steps of tenths, in buffered saline:

| Dilution | pg per µl | ng per cup (25 µl per cup) |
|---|---|---|
| 1:25 | 40,000 | 1,000 |
| 1:250 | 4,000 | 100 |
| 1:2,500 | 400 | 10 |
| 1:25,000 | 40 | 1 |
| 1:250,000 | 4 | 0.1 |

2. Proceed to V and VI, then return to IV, $B_2$ when the results of the preliminary assay are available.

Note: Only 20 larvae per dose level will be needed for a preliminary assay (no replicates).

$B_2$. Procedure

This procedure should be used if an approximate estimate of the infectivity titer of the virus preparation is available, or if a preliminary $LC_{50}$ has been determined by means of a range finding assay ($B_1$, above).

1. Prepare five serial dilutions of the stock suspension in steps of one-half, in buffered saline. These dilutions must be computed so that two of the dose levels will be above the preliminary or estimated $LC_{50}$, one at about the estimated $LC_{50}$ level, and two below the $LC_{50}$ level.

Example:
From the data gathered in an exploratory assay, we estimate that the $LC_{50}$ is approximately 5 nanograms of preparation per cup. The following dilution steps will then be considered appropriate for a bioassay:

| Dose level | ng per cup (25 µl per cup) | pg per µl | Dilution |
|---|---|---|---|
| 1 | 20 | 800 | 1:1,250 |
| 2 | 10 | 400 | 1:2,500 |
| 3 | 5 | 200 | 1:5,000 |
| 4 | 2.5 | 100 | 1:10,000 |
| 5 | 1.25 | 50 | 1:20,000 |

## V. INOCULATION OF THE TEST CUPS

A. Materials and equipment
1. Analyzer cups with diet (see I)
2. Racks for analyzer cups
3. Perforated caps for analyzer cups. Caps (Scientific Products diSPo beaker cap, polyethylene, B2716-1) are perforated with a hot needle, washed in distilled water, dried, placed in plastic petri dishes (20 per dish), and exposed in a UV sterilizer for 30 min.
4. Second-instar larvae (see II)
5. Dilute virus suspensions (see IV)
6. Sterile toothpicks
7. Infectivity test record charts (figs. 1 and 2)
8. 25-µl pipet with sterile tips
9. Sterile hood
10. Ultraviolet sterilizer
11. 30°C incubator

FSL Corvallis (Martignoni)

| EVALUATE | COMPLETED | SUMMARY | COMPUTER | 532 |
|---|---|---|---|---|

Purpose _____

Species _____ Stage, instar, mg _____

Source of insects _____ Gener. _____ Temp. _____ Diet _____

Inoculum _____ Volume _____ Route _____

Other data Container

| No. | Date treat. | Inoculum | Date dead | S | P | Diagnosis | ST | L |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| 2 | | | | | | | | |
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| 4 | | | | | | | | |
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| 20 | | | | | | | | |

Dates checked and initials S= sacrificed ST= survival time (days) L= live at completion

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*Figure 1.--Record chart for infectivity tests.*

FSL Corvallis (Martignoni) Continuation sheet 532

| No. | Date treat. | Inoculum | Date dead | S | P | Diagnosis | ST | L |
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Dates checked and initials

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*Figure 2.--Record chart for infectivity tests (continuation sheet).*

B. Procedure

1. Remove the analyzer cups from the refrigerator at least two hours before the surface of the diet is to be inoculated.
2. Place 20 analyzer cups in each rack.
3. Number the cups (test number and cup number).
4. Place the racks with the cups under a sterile hood, for about 2 hours, to eliminate condensation droplets.
5. Shake vigorously the most dilute of the five suspensions and dispense 25 µl in each of five cups (fig. 3).

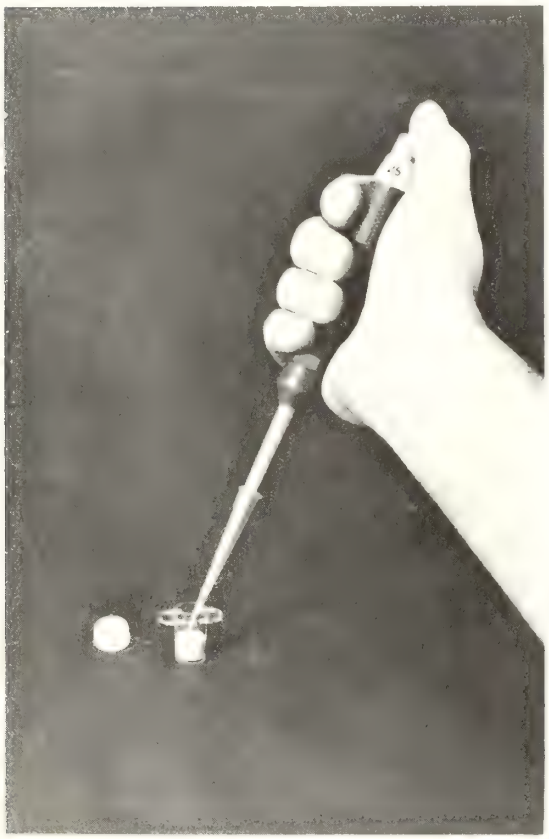

*Figure 3.--Pipetting 25 µl of a dilute virus suspension on the diet surface in an analyzer cup.*

6. Swirl the inoculum in the analyzer cups, making certain that the entire diet surface is wet.
7. Shake the suspension and proceed to dispense 25 µl to each of five additional cups. Swirl the inoculum.
8. Continue until 40 cups have been inoculated. Place the cups under a sterile hood (no light), at room temperature, for a minimum of 1 hour or until the diet surface is dry.
9. Repeat the above steps (5 to 8) with each of the other virus suspensions, in order of increasing concentration. For five serial dilutions, 200 cups will be needed. (Forty additional cups will serve as uninoculated controls.)
10. With a toothpick, transfer one second-instar larva to each cup and cap the cups with a perforated lid (figs. 4 and 5).
11. Place the cup racks on trays so that the cups are in horizontal position. Place the trays in a 30°C incubator, for 12 days, in darkness (fig. 6).
12. Complete the infectivity test record charts.

Note: Only 20 larvae per dose level will be needed for a preliminary assay (no replicates).

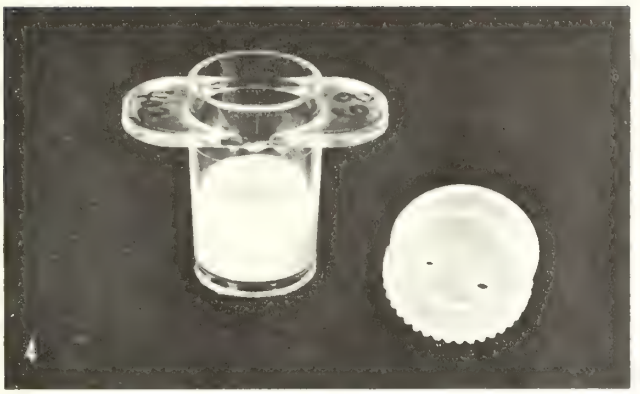

*Figure 4.--Analyzer cup with 1 ml of diet 65-W-PEN and perforated cap.*

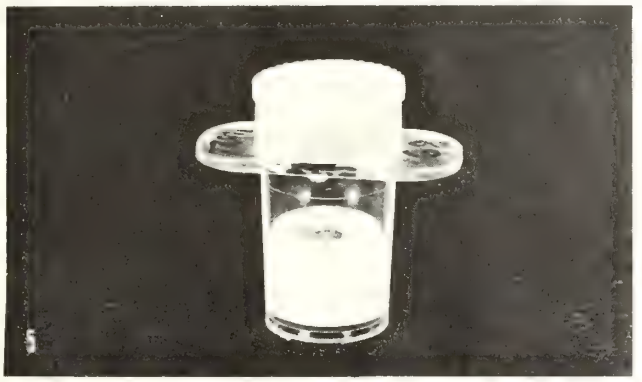

*Figure 5.--Capped analyzer cup with 1 ml of diet 65-W-PEN and 1 second-instar test larva.*

*Figure 6.--Trays, with cup racks and inoculated test cups (with larvae), in a 25°C incubator.*

## VI. EVALUATION

1. Daily, record the deaths on the infectivity test charts, during a 12-day observation period.
2. Usually the diagnosis (nucleopolyhedrosis) is readily apparent by macroscopic examination of the dead larva. In a few instances, however, a microscopic examination of larval tissues (to include epidermis, fat body, and tracheae) may be necessary. The cause of death is recorded on the infectivity test charts.
3. At the end of the 12-day observation period, tabulate the results as follows:

| Dose ng per cup | Group | Number of test larvae | Number of dead larvae (nucleopolyhedrosis) | Mortality rate % |
|---|---|---|---|---|
| 1.25 | A | 20 | 2 | 10 |
| | B | 20 | 1 | 5 |
| 2.50 | A | 20 | 4 | 20 |
| | B | 20 | 5 | 25 |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |

$4_a$. If the data are from a preliminary (or range-finding) assay (IV, $B_1$) and the mortality rate for two of the five dose levels falls between 10 and 90 percent, draw a line through the two points, on Berkson's logarithmic logistic ruling graph paper (Codex No. 32-450 or 32-454). Read the $LC_{50}$ (ng/cup) from the plotted line. If only one point falls between 10 and 90 percent, draw a line through this point, with a slope of 3. Read the $LC_{50}$ from the plotted line. Resume IV, $B_2$.

$4_b$. If the data are from a conclusive assay (IV, $B_2$), compute the $LC_{50}$ on Berkson's graph paper (see above) or by minimum logit chi-square analysis (Berkson 1953; LOCSAN program by R. L. Giese, Purdue University). The program's printout lists the $LC_{50}$ (ng/cup), the 95-percent fiducial limits, the slope of the regression line, and tests for linearity and homogeneity of response among the test insects.

## VII. CHECKLIST OF ITEMS NEEDED FOR ONE BIOASSAY

Aluminum foil
Aspirator, rubber, for pipets
Balance, analytical
Blender, semi-micro
Blender base, two-speed motor
Caps, perforated, for analyzer cups (240)
Coverslips
Cups, analyzer, 2-ml (240)
Cylinder, measuring, 50-ml, sterile
Diet, insect, 65-W-PEN (400 ml)
Dishes, petri, 100- x 15-mm, disposable (24)
Flask, Erlenmeyer, 125-ml, sterile
Graph paper, logarithmic logistic ruling
Hot plate
Incubator, 30°C
Instruments, dissecting (set)
Hood, sterile
Labels, adhesive (24)
Larvae, second-instar (240)
Microscope
Paper tissues, sterile
Pipet, 25-microliter
Pipets, 1-ml, sterile, disposable (3)
Pipets, 5-ml, sterile, disposable (6)
Pipet, 10-ml, sterile, disposable
Pipet, 10-ml, wide-tip, sterile, disposable
Racks, for analyzer cups (12)
Record charts, infectivity test (one initial sheet, nine continuation sheets)
Refrigerator
Saline, buffered, sterile (100-ml)
Slides, microscope (box)
Spatula, micro, sterile
Sterilizer, UV
Thermometer, 60°C
Tips, for microliter pipet, sterile (12)
Toothpicks, sterile (box)
Trays, for analyzer cup racks (1 ten-rack, 1 two-rack)
Vials, screw-cap, 20-ml, sterile (7)
Virus preparation (50 mg)
Water bath

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Martignoni, Mauro E., and Paul J. Iwai.
1977. Peroral bioassay of technical-grade preparations of the Douglas-fir tussock moth nucleopolyhedrosis virus *(Baculovirus)*. USDA For. Serv. Res. Pap. PNW-222, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The potency of industrial preparations of viruses for control of injurious insects can be estimated reliably only by means of biological assay. We describe a simple, yet sensitive peroral bioassay procedure for technical-grade preparations of nucleopolyhedrosis virus. This procedure has been accepted by the Forest Service and the U.S. Environmental Protection Agency as the standard method for assaying industrial virus preparations for control of the Douglas-fir tussock moth.

KEYWORDS: Bioassay, nucleopolyhedrosis, virus (insect), virus (-insecta, virus (-forest pest control, insect diseases, diseases (insect), insect damage control (forest), biological control (-forest pests, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

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1977
USDA FOREST SERVICE RESEARCH PAPER PNW-223

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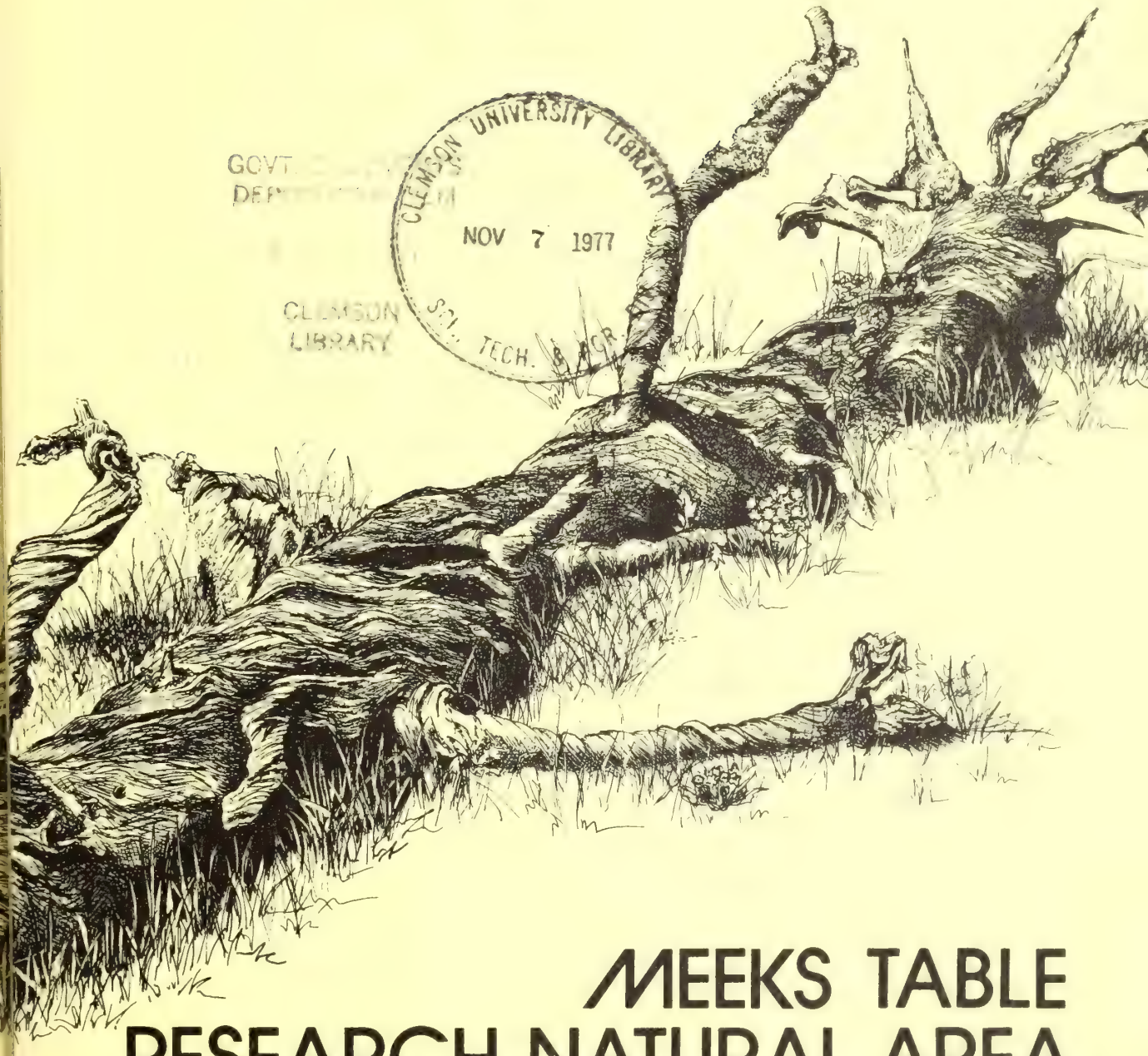

# MEEKS TABLE RESEARCH NATURAL AREA

## REFERENCE SAMPLING AND HABITAT CLASSIFICATION

Arthur R. Tiedemann and
Glen O. Klock

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

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MEEKS TABLE

# MEEKS TABLE RESEARCH NATURAL AREA--
# REFERENCE SAMPLING AND HABITAT CLASSIFICATION

*Reference Abstract*

Tiedemann, Arthur R., and Glen O. Klock.
1977. Meeks table research natural area--reference sampling and habitat classification. USDA For. Serv. Res. Pap. PNW-223, 19 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Studies of vegetation cover and composition and physical and chemical characteristics of soil indicate the presence of three shrub-grass and two forested communities on Meeks Table Research Natural Area. Development of these communities appears to be linked to depth of volcanic ash.

KEYWORDS: Research Natural Areas, Meeks Table Research Natural Area, soil nutrients, communities (plant), habitat classification.

*RESEARCH SUMMARY*

*Research Paper PNW-223*

*1977*

Similarity analyses of cover and composition of shrub and herbaceous vegetation and comparisons of physical and chemical soil properties on Meeks Table Research Natural Area indicate the presence of three shrub-grass and two forested communities on three dominant soil associations and two subassociations. Shrub-grass communities in order of degrees of development and amount of vegetal cover are *Artemisia/Poa/Eriogonum*, *Artemisia/Poa/Sedum*, and *Artemisia/Stipa/Phlox*. The two forested communities are *Pinus/Calamagrostis/Lupinus* and *Abies/Calamagrostis/Arnica*. Development of vegetation communities appears to be closely linked to the depth of volcanic ash and climatic factors (wind and water erosion) that have governed the stability of ash deposits.

Levels of plant nutrients in the upper 7.5 cm of soil generally increased in the order *Artemisia/Poa/Eriogonum* < *Abies/Calamagrostis/Arnica* < *Artemisia/Poa/Sedum* ≤ *Artemisia/Stipa/Phlox* < *Pinus/Calamagrostis/Lupinus*. Because of differences in soil depths among communities, total quantities of nutrients were arrayed as follows: *Artemisia/Poa/Eriogonum* < *Artemisia/Poa/Sedum* < *Abies/Calamagrostis/Arnica* ≤ *Artemisia/Stipa/Phlox* < *Pinus/Calamagrostis/Lupinus*.

These differences in levels and total capitals of nutrients among communities suggest a need to determine relationships among soil nutrient levels, soil nutrient availability, and biomass productivity of forest and range sites of the eastern Cascades as a basis for understanding effects of land use practices on future site productivity.

## Introduction

Intensified use and manipulation of wildlands in recent years have focused attention on the need to maintain productive, stable, high quality resource management programs. Such programs require characterization of the undisturbed environment for each ecosystem being managed. Baseline vegetation and soils data, two basic components of environmental information, can be collected on Research Natural Areas established for this purpose. Research Natural Areas on Federal lands provide examples of ecosystems in essentially natural conditions. These areas can be used for the collection of baseline data and long term monitoring of environmental quality; studies of the structure and function of natural ecosystems; preservation of gene pools of natural organisms; and education and training (Franklin et al. 1972, Moir 1972, and Romancier 1974).

Meeks Table, a 27-ha isolated basalt-capped plateau, was established as a Research Natural Area in 1948 to exemplify undisturbed east Cascade *Pinus ponderosa-Pseudotsuga menziesii-Calamagrostis rubescens* and associated shrub-grass habitats on soils derived from basalt parent material (Tiedemann et al. 1972). The area was never logged or grazed. There is, however, a history of periodic fire on the table.

Since the area was established, there are new classifications for forest and steppe vegetation for eastern Washington (Daubenmire and Daubenmire 1968, Daubenmire 1970), and a comprehensive description of the vegetation in Oregon and Washington (Franklin and Dyrness 1973).

This study was conducted to describe and classify the communities of Meeks Table, generate reference level (baseline) information on vegetation and soils of each described community, and focus on the management implications of the baseline information.

## Previous Work

Rummell (1951) was instrumental in establishing Meeks Table as a Research Natural Area and conducted the first documented study of the vegetation and soils of the area. The objective of his study was to determine the effects of grazing on regeneration of ponderosa pine. His approach was to compare vegetation and soils of ungrazed Meeks Table with those of adjacent Devil's Table where livestock use was occurring. Neither area had been logged. In his study he recognized three vegetative communities on Meeks Table: *Pinus ponderosa/Calamagrostis rubescens-Carex geyeri*, *Pseudotsuga menziesii/C. rubescens-C. geyeri*, and *Stipa occidentalis-Poa sandbergii*. Rummell noted striking differences in density (cover) of *C. rubescens* between Meeks and Devil's Tables. He concluded that tree reproduction on Meeks Table was sparse because of the dense herbaceous cover, whereas tree reproduction was abundant on Devil's Table where heavy grazing had reduced the cover of understory vegetation.

Rummell also described typical soil profiles for the forested and open grassland communities of Meeks Table. From his observations, soils in forested areas can be classed as andic xerochrepts. Soils in grassland areas are lithic xerochrepts. 1/

Studies of a similar nature have been conducted by Jameson et al. (1962) and Schmutz et al. (1967) for isolated plateaus in Arizona. Both studies utilized comparisons between the isolated, undisturbed area and

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1/ Personal communications from Mr. Philip McColley and Mr. Robert Mitchell, Soil Scientists, Wenatchee and Umatilla National Forests, respectively.

mainland conditions where use was occurring. Vegetative composition between isolated and mainland conditions was strikingly different in both studies.

## Physical Environment

Meeks Table is an isolated, flat-topped butte rising 150 m above the surrounding rolling terrain (fig. 1). It is a remnant of a larger plateau isolated by river action. Elevation on the table varies from 1 280 to 1 585 m. Access is by a steep, narrow trail up the knife-like ridge at the northwest end.

*Figure 1.--Meeks Table Research Natural Area - a 27-ha isolated, basalt-capped plateau.*

A modified continental climate prevails. Most precipitation occurs as snow during the cool, cloudy winter. Summers are warm, generally low in precipitation, and largely cloudless. One to 3 months of drought are common. United States Weather Bureau (1965) climatic data from Bumping Lake located at 1 400-m elevation in a valley 16 km west of Meeks Table are as follows:

| | |
|---|---|
| Mean annual temperature..... | 4.7°C |
| Mean January temperature..... | -4.9°C |
| Mean July temperature..... | 14.5°C |
| Mean January minimum temperature.. | -10.0°C |
| Mean July maximum temperature..... | 23.6°C |
| Average annual precipitation.... | 1 214. mm |
| July through August precipitation.. | 69. mm |
| Average annual snowfall..... | 554. cm |

## Methods

In July 1968 vegetative cover and composition were sampled on 48 plots spaced at 50-m intervals from a random start along four lines traversing the table from northwest to southeast. Cover and compostion of herbaceous and shrubby vegetation were measured with a 100-pin point frame 60 x 60 cm (Brown 1954). Using the center of the point frame as a plot center, cover of tree overstory was measured with a spherical densiometer. Height of the tallest tree and diameter at breast height of all trees on a 0.08-ha circular plot was recorded by species.

Soil cores and loose soil samples were collected on every third plot to a depth of 7.5 cm at the plot center.

Chemical analyses of soils conducted were: pH and total carbon (Black et al. 1965a); total N (Keeney and Bremner 1967); total S (Tiedemann and Anderson 1971); cation exchange capacity (Chapman and Pratt 1961, Ballentine and Gregg 1947); exchangeable cations by atomic absorption spectroscopy (Robinson 1966). Physical analyses were: bulk density, texture, aggregate stability, and available soil moisture (Black et al. 1965b).

Vegetation and soils were highly variable among plots on these transects.

Stratification of plots into groups with similar overstory and understory vegetation indicated the presence of three shrub-grass and two forested communities. These tentative communities were:

*Artemisia rigida/Poa sandbergii/ Eriogonum douglassii*

*A. rigida/P. sandbergii/Sedum stenopetallum*

*A. rigida/Stipa occidentalis/ Phlox diffusa*

*Pinus ponderosa/Calamagrostis rubescens/Lupinus laxiflorus*

*Abies grandis/Calamagrostis rubescens/ Arnica cordifolia*

Soils data indicate that these five plant communities reflect the growth response on three dominant soil associations with two of the three associations stratified into two subassociations.

Sampling of herbaceous and shrubby vegetation was stratified for the second occasion to provide a more adequate sample. Numbers of plots needed to be within 10 percent of the true mean for 90 percent of the time were determined for each tentative community using mean ($x$) and variance ($s^2$) of understory vegetative cover from the first sample occasion for one or two herbaceous or shrubby species with frequency greater than 60 percent. This choice will no doubt lessen the confidence of measurements on species with lower frequencies. There were not sufficient data, however, on samples with lower frequencies for a valid estimate of $s^2$. Also, the high variability among plots would have resulted in an unreasonable requirement for number of plots. Variability of soil nitrogen within each tentative community was the criterion used to determine number of soil samples needed.

The second sample of understory vegetation was taken using a 20-pin point frame 60 x 120 cm. In addition to foliar hits by pins for vegetal cover, presence of each species in the confines of the 60- x 120-cm plot was recorded for frequency.

Plots were systematically spaced 11 m apart by random direction from the center of each tentative community until another community was encountered or the desired number of plots taken. Each tentative community was represented by several discrete units on the table and each unit was sampled.

Size distribution among tree species was determined in August 1975 for the two forested communities by measuring d.b.h. of all trees on six 25- x 25-m plots in the *Pinus* community and seven 25- x 25-m plots in the *Abies* community. Data from the 1968 sample of tree species were not included because many of the plots encompassed more than one community and would not accurately represent the individual forested communities.

Soil samples were collected in each tentative community with the randomization technique used for vegetation sampling. Where possible, soil cores were collected from 0 to 7.5 cm, 15 to 22.5 cm, and 30.5 to 38 cm. Samples were analyzed as described earlier. Shrub and herbaceous vegetation data were summarized by cover and frequency. Indices of similarity among the 186 individual plots were computed (Oosting 1956) using

$$c = \frac{2w}{a + b} \times 100;$$

where,

$c$ = percent similarity,
$a$ = sum of quantitative measures of plants in one stand,
$b$ = sum of quantitative measures of plants in a second stand,
$w$ = sum of the lesser value for those species in common between the two stands.

No frequency data were generated for vegetation within individual plots. A dendogram was constructed to enable a more objective separation of communities (Mueggler and Harris 1969). Indices of similarity were also calculated among tentative communities using frequency of individual plant species.

Differences in soil properties among communities were evaluated using analysis of variance and a Duncan multiple range test for separation of means (Steel and Torrie 1960).

## Results and Discussion

### VEGETATION

Similarity analyses and the dendogram for the entire 186 plots resulted in numerous clusters of plots at any selected similarity value greater than 20 or 30 percent. Cover values from the point frame data were apparently not sensitive enough to enable us to make community separations from similarity analyses among the 186 plots. Mueggler and Harris (1969) also found that ordinations of grassland sites failed to group areas over the 30-percent level of similarity. They concluded that this was an indication of non-uniformity among sites and strong sensitivity of the vegetation to site dissimilarities. We next made similarity comparisons among the five tentative communities using frequency of individual species within each community (table 1).

Similarity among the three shrub-grass communities ranged from 41 to 59 percent. Similarity of shrub-grass to forested communities for understory vegetation ranged from 5 to 16 percent. The two forested communities had a similarity of 51 percent. Thus, if 60 percent is established as a reasonable level of similarity at which two communities are the same, there are five distinct communities on Meeks Table.

Table 1--*Similarity matrix for five communities on Meeks Table*

| | *Artemisia/ Stipa/ Phlox* | *Artemisia/ Poa/ Eriogonum* | *Artemisia/ Poa/ Sedum* | *Pinus Calamagrostis/ Lupinus* | *Abies/ Calamagrostis/ Arnica* |
|---|---|---|---|---|---|
| *Artemisia/ Stipa/ Phlox* | 100 | 41 | 59 | 16 | 11 |
| *Artemisia/ Poa/ Eriogonum* | | 100 | 49 | 7 | 5 |
| *Artemisia/ Poa/ Sedum* | | | 100 | 10 | 9 |
| *Pinus Calamagrostis/ Lupinus* | | | | 100 | 51 |
| *Abies Calamagrostis/ Arnica* | | | | | 100 |

The *Artemisia rigida/Poa sandbergii/ Eriogonum douglassii* community covers 3 ha and occupies almost the entire southern rim of Meeks Table (fig. 2). It is characterized by a harsh, rocky, poorly developed soil with sparse vegetative cover (20 percent) (fig. 3). We documented 32 plant species in this

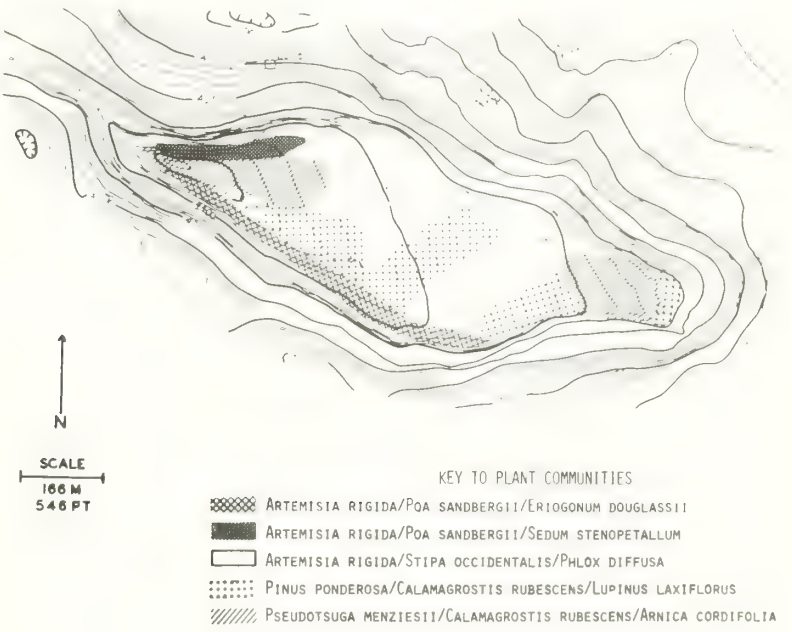


*Figure 2.--Distribution of plant communities on Meeks Table Research Natural Area. Contour interval is 6 m (20 ft).*

*Figure 3.--The Artemisia/ Poa/Eriogonum community is characterized by a harsh, rocky, poorly developed soil and sparse vegetative cover.*

community, many of which Daubenmire (1970) includes in his descriptions of lithosolic habitats (table 2). *Artemisia rigida*[2/] provides only 1.5-percent cover, but is the principal shrubby species in this community. *Purshia tridentata* cover is 2.9-percent, but this species occurs primarily in a transition with the *Pinus ponderosa* community.

*Poa sandbergii* was found on 93 percent of the plots and provides 2.2-percent ground cover. *Sitanion hystrix* var. *hordeoides* and *Bromus tectorum*, two species common to harsh, rocky sites in the Pacific Northwest, provide 1.2- and 0.9-percent cover, respectively. The most ubiquitous forbs are *Eriogonum douglasii*, *Antennaria dimorpha*, and *Penstemon gairdneri*. *Lewisia rediviva*, a harsh site indicator plant, was found on 28 percent of the plots. This community appears to be analogous to the *Artemisia rigida/Poa* or *Eriogonum/Poa* habitat types described by Daubenmire (1970), and is similar to the *Artemisia/Poa/Eriogonum* communities described by Hall (1973) in the Blue Mountains of Oregon. Hall notes that good condition range of this type has the same appearance as poor condition *Artemisia tridentata* range.

The extreme northern rim at the western end of the table supports a 1-ha community of *Artemisia rigida/Poa sandbergii/Sedum stenopetalum*. This area differs principally from the southern rim in greater total vegetative cover (28.5 percent), conspicuously less cover and lower frequency of *L. rediviva*, *P. sandbergii*, and *P. gairdneri*, and greater cover and frequency of *Arenaria congesta*, *Lupinus laxiflorus*, *Danthonia unispicata*, and *Stipa occidentalis* (fig. 4).

The most extensive area on the table is the *Artemisia rigida/Stipa occidentalis/Phlox diffusa* community occupying 11 ha of the center and northern rim in large openings between forested communities (fig. 5). Average vegetal cover of this community is 45 percent. Of the 53 species found here, *S. occidentalis* is the most abundant, providing nearly one-fourth of the total cover with 90-percent frequency of occurrence. *Artemisia rigida* provides 3.8-percent cover and has a frequency of 49 percent. Cover of *P. diffusa* is 4.3 percent and frequency is 50 percent. One especially notable feature of this community is the abundance of annual plants such as *Cryptantha torreyana*, *Polygonum kelloggii*, *Linanthus harknessii*, and *Collinsia parviflora*. Daubenmire (1970) and Meuggler and Harris (1969) indicate that abundant annuals are a normal part of the vegetation complex of these grassland communities--even in an undisturbed state. Several of the habitat types described by Daubenmire (1970) include *S. occidentali* but cover and frequency were lower than we observed on Meeks Table. According to Franklin and Dyrness (1973), this community is an early stage of retrogression of *Agropyron* and *Festuca* associations in response to grazing of eastern foothills of the Cascade Range in Washington. Tiedemann (1972) found extensive areas of *S. occidentalis* at elevations of 1 850 m on Table Mountain, a basalt-capped plateau in central Washington, which has a history of use by both sheep and cattle.

The observed abundance of *S. occidentalis* on Meeks Table indicates that this plant may be a major component of developing shrub-grass communities, as well as an early indicator of retrogression from climax of *Agropyron* and *Festuca* communities in response to livestock use.

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[2/] Species determinations by Drs. F. J. Hermann and C. Feddema, U.S. Forest Service Herbarium, Fort Collins, Colorado. Plant nomenclature follows Hitchcock and Cronquist (1973).

Table 2--*Percent cover and frequency of shrub and herbaceous vegetation on Meeks Table*

| Species | *Artemisia/Poa/ Eriogonum* | | *Artemisia/Poa/ Sedum* | | *Artemisia/Stipa/ Phlox* | | *Pinus/Calamagrostis/ Lupinus* | | *Abies/Calamagrostis/ Arnica* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cover | Frequency (40 plots) | Cover | Frequency (10 plots) | Cover | Frequency (76 plots) | Cover | Frequency (30 plots) | Cover | Frequency (30 plots) |
| SHRUBS | | | | | | | | | | |
| *Artemisia rigida* | 1.5 | 28 | 1.0 | 20 | 3.8 | 49 | | | | |
| *Purshia tridentata* | 2.9 | 15 | | | | | | | | |
| *Arctostaphylos uva-ursi* | | | | | 0.8 | 3 | | | | |
| *Holodiscus discolor* | | | | | | | | 3 | 0.5 | 11 |
| *Amelanchier alnifolia* | | | | | | | | | | 3 |
| Total shrubs | 4.4 | | 1.0 | | 4.6 | | | | | |
| GRASSES AND SEDGES | | | | | | | | | | |
| *Bromus tectorum* | 0.9 | 58 | | | | | | | | |
| *Poa sandbergii* | 2.2 | 93 | 0.5 | 20 | 1.7 | 71 | | | | |
| *Sitanion hystrix* var. *hordeoides* | 1.2 | 33 | 0.5 | 20 | 0.5 | 33 | | | | |
| *Stipa occidentalis* var. *minor* | 0.2 | 20 | 1.5 | 60 | 10.1 | 90 | | | | |
| *Danthonia unispicata* | | 18 | 1.0 | 40 | 0.9 | 21 | | | | |
| *Festuca idahoensis* | 0.1 | 5 | 0 | 10 | 0.1 | 3 | | | | |
| *Koeleria cristata* | 0 | 5 | | | 0.1 | 4 | | | | |
| *Carex geyeri* | 0 | 3 | 1.5 | 40 | 0.8 | 18 | 11.0 | 90 | 12.5 | 97 |
| *Bromus marginatus* | | | | | 0.4 | 12 | 1.2 | 3 | | |
| *Calamagrostis rubescens* | | | | | 2.4 | 13 | 42.7 | 100 | 19.5 | 77 |
| *Danthonia intermedia* | | | | | | | 0.2 | 3 | 0 | 3 |
| Total grasses and shrubs | 4.6 | | 5.0 | | 17.0 | | 55.1 | | 32.0 | |
| FORBS AND HALFSHRUBS | | | | | | | | | | |
| *Haplopappus stenophyllus* | 0.3 | 18 | | | | | | | | |
| *Lewisia rediviva* | 0.1 | 28 | | | | | | | | |
| *Erigeron bloomeri* | 0.4 | 48 | 2.5 | 50 | | | | | | |
| *Allium acuminatum* | 0.1 | 35 | | | | 11 | | | | |
| *Penstemon gairdneri* | 1.0 | 43 | | | 0.3 | 18 | | | | |
| *Antennaria dimorpha* | 1.6 | 65 | 1.5 | 40 | 0.5 | 16 | | | | |
| *Agoseris glauca* | 0.1 | 3 | 0 | 10 | 1.0 | 59 | | | | |
| *Balsamorhiza sagitatta* | 0.1 | 3 | | 10 | | 5 | | | | |
| *Castilleja thompsonii* | 0.3 | 5 | 0 | 10 | 0.3 | 33 | | | | |
| *Eriogonum compositum* | 0.4 | 3 | 0 | 20 | | 8 | | | | |
| *Eriogonum douglasii* | 2.4 | 65 | 1.5 | 20 | | 1 | | | | |
| *Phlox diffusa* | 0.9 | 28 | 0.5 | 30 | 4.3 | 50 | | | | |
| *Polygonum kelloggii* | | 3 | 0.5 | 50 | 0.7 | 50 | | | | |
| *Viola trinervata* | 0.2 | 23 | | 20 | | 4 | | | | |
| *Arenaria congesta* | 0.8 | 70 | 2.5 | 100 | 0.9 | 43 | 0 | 3 | | |
| *Collinsia parviflora* | 0 | 8 | 0 | 90 | 0.1 | 47 | 0 | 3 | | |
| *Lomatium nudicaule* | 0.6 | 8 | 0.5 | 50 | 2.0 | 84 | 0.2 | 3 | | |
| *Sisyrinchium douglasii* | 0.4 | 10 | 2.0 | 70 | 1.3 | 41 | 0.2 | 7 | | |
| *Sedum stenopetalum* | 0.6 | 63 | 4.5 | 100 | 1.4 | 84 | | 3 | | |
| *Antennaria rosea* | 0.5 | 23 | | | 0.4 | 16 | 0.2 | 10 | | |
| *Cryptantha torreyana* | 0 | 23 | 0 | 10 | 1.4 | 95 | 0 | 7 | | |
| *Lupinus laxiflorus* | 0.1 | 5 | 4.0 | 50 | 1.2 | 37 | 8.3 | 97 | 1.5 | 43 |
| *Achillea millefolium* | | | | 10 | 0.1 | 28 | 3.3 | 63 | 0.7 | 13 |
| *Lithophragma bulbifera* | | | | 10 | | 7 | | | | |
| *Lomatium dissectum* | | | | 30 | 0.8 | 41 | | | | |
| *Antennaria luzuloides* | | | 2.5 | 30 | 2.6 | 49 | | | | |
| *Haplopappus lanuginosus* | | | 0 | 10 | 0.1 | 9 | | | | |
| *Anaphalis margaritacea* | | | | | | 3 | 0.8 | 50 | | |
| *Fritillaria pudica* | | | | | | 1 | 0.3 | 23 | | |
| *Geum triflorum* | | | | | 0.1 | 11 | 0.7 | 20 | | |
| *Hieracium cynoglossoides* | | | | | 0.1 | 12 | 0.7 | 40 | | |
| *Silene oregana* | | | | | | 3 | | 3 | | |
| *Arnica fulgens* | | | | | | 4 | | | 0.3 | 7 |
| *Antennaria racemosa* | | | | | 0.1 | 3 | | | | |
| *Agoseris heterophylla* | | | | | 0.1 | 4 | | | | |
| *Arabis divaricarpa* | | | | | 0.1 | 1 | | | | |
| *Castilleja miniata* | | | | | 0.2 | 7 | | | | |
| *Crepis* spp. | | | | | 0.2 | 3 | | | | |
| *Erigeron linearis* | | | | | 1.1 | 29 | | | | |
| *Haplopappus carthamoides* | | | | | | 1 | | | | |
| *Linanthus harknessii* | | | | | 0.6 | 50 | | | | |
| *Madia glomerata* | | | | | 0.9 | 41 | | | | |
| *Potentilla fruticosa* | | | | | 0.1 | 5 | | | | |
| *Phacelia sericea* | | | | | 0.1 | 5 | | | | |
| *Zigadenus paniculatus* | | | | | 0.3 | 15 | | | | |
| *Arnica cordifolia* | | | | | | | 3.0 | 7 | 6.8 | 90 |
| *Erythronium grandiflorum* | | | | | | | 0.7 | 47 | 0.7 | 40 |
| *Epilobium angustifolium* | | | | | | | 0 | 7 | 0.5 | 20 |
| *Frasera speciosa* | | | | | | | 1.5 | 23 | 1.0 | 13 |
| *Pedicularis racemosa* | | | | | | | | 10 | | 3 |
| *Lomatium triternatum* | | | | | | | | 17 | | 3 |
| *Potentilla arguta* | | | | | | | 0.3 | 3 | | |
| *Luina nardosmia* | | | | | | | | | 0.2 | 3 |
| *Osmorhiza chilensis* | | | | | | | | | | 1/p |
| *Chimaphila umbellata* | | | | | | | | | | 1/p |
| *Arenaria macrophylla* | | | | | | | | | 0.7 | 10 |
| *Pachistima myrsinites* | | | | | | | | | | 1/p |
| Total forbs and halfshrubs | 10.9 | | 22.5 | | 23.7 | | 20.2 | | 12.4 | |
| Total all classes | 19.9 | | 28.5 | | 45.3 | | 75.3 | | 44.9 | |

1/ Present in the community but not found in any plot.

*Figure 4.--The Artemisia/Poa/Sedum community on the north rim of Meeks Table.*

Figure 5.--The *Artemisia/Stipa/Phlox community occupies large openings between forested areas.*

The *Pinus ponderosa/Calamagrostis rubescens/Lupinus laxiflorus* community occupies 7 ha and has a density of 192 trees per ha (fig. 6). Cover of the overstory averages 26 percent but is as great as 70 percent in places. Density of *P. ponderosa* ranged from 30 to 50 trees per ha among the size classes from 1 to 80-cm d.b.h. (fig.7). Density of trees greater than 80 cm dropped sharply. *Pseudotsuga menziesii* represents less than 10 percent of the total tree density in this community.

*Figure 6.--Savannah-like appearance of the Pinus/Calamagrostis/Lupinus community.*

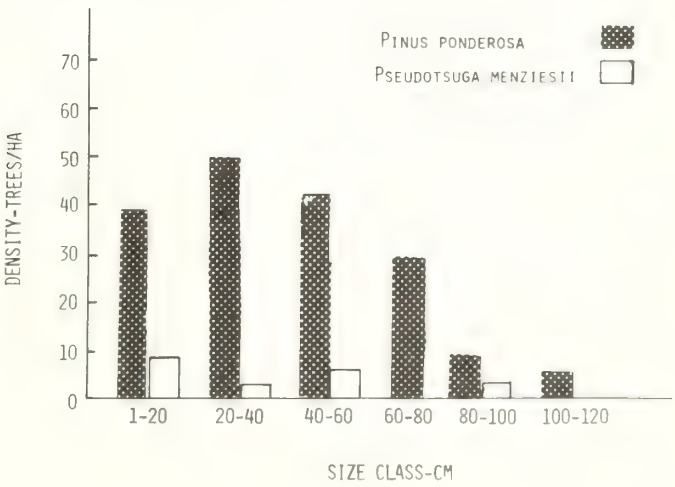


*Figure 7.--Density of tree species by size class in the Pinus/Calamagrostis/Lupinus community.*

Reproduction in this community was sparse for both species, but especially for *P. menziesii*, as shown by densities in the 1- to 20-cm class.

Cover of understory vegetation is 75 percent and clearly dominated by *C. rubescens* (43-percent cover) and *Carex geyeri* (11-percent cover). These two species comprise two-thirds of the understory cover. *Calamagrostis rubescens* frequency was 100 percent. *Lupinus laxiflorus* is the most abundant forb.

The *Abies grandis/Calamagrostis rubescens/Arnica cordifolia* community is strikingly different from the *Pinus/Calamagrostis/Lupinus* community in composition and cover of both overstory and understory and in tree density (fig. 8). This community occupies 6 ha and has a tree density of 480 stems per ha (fig. 9). The majority of trees (293 per ha) are *P. menziesii*. *Abies grandis*, *P. ponderosa*, and *Larix occidentalis* comprise the major portion of the remaining stems. *Picea engelmannii* and *P. contorta* are minor components of the tree composition with densities of three trees per ha. Tree cover ranges from 20 to 100 percent and averages 51 percent. For this percentage of tree cover, 45-percent foliar cover of understory vegetation is surprisingly high. More than three-fourths of this cover is *C. rubescens* (19.5 percent) and *C. geyeri* (12.5 percent). *Arnica cordifolia* Hook. is the predominant forb, providing 6.8-percent cover with 90-percent frequency. We classified this community as an *Abies/Calamagrostis/Arnica* community because *A. grandis* is present and reproducing and because of the dominance of *C. rubescens* and *A. cordifolia* in the understory. This association appears to be analagous to those occurring on volcanic and ash soils in the Blue and Ochoco Mountains described by Franklin and Dyrness (1973). The community has a strong affinity for *Pseudotsuga/Abies/Calamagrostis* on ash soil described by Hall (1973) in the Blue Mountains. According to Franklin and Dyrness, any of the four common associates, *P. menziesii*, *Larix occidentalis*, *P. ponderosa*, or *P. contorta*, may dominate seral forest stands of this association.

There are some differences between our observations and those of Rummell (1951). Rummell lists only three communities because he did not measure vegetation of the south or north rims. The *Stipa occidentalis/Poa sandbergii* open grassland type he described is the same as the *Artemisia/Stipa/Phlox* community of the present study. The open *P. ponderosa*, *P. menziesii* with *C. rubescens* and *C. geyeri* understory appears to be the same as the *Abies/Calamagrostis/Arnica* community.

The most important differences between the two studies were in numbers of species encountered and amount of vegetative coverage in each community. We encountered twice as many species in the *Artemisia/Stipa/Phlox* community as Rummell. This difference can likely be attributed to time of sampling. Our sampling was in late June when bulbous vernal perennials such as *Sisyrinchium* sp. and *Fritillaria pudica* were still identifiable and annuals such as *Polygonum kelloggii*, *Cryptantha torreyana* and *Madia glomerata* were at their peak development. Rummell did not indicate time of sampling; but since he lists none of the bulbous plants and only two of the annuals, it was likely in late summer. Cover of shrubby and herbaceous vegetation was approximately double the values obtained by Rummell. Disparities in vegetative cover between the two studies are probably a result of a difference in method of measurement. Rummell used the square-foot density method from Stewart and Hutchings (1936) for plots 100 square feet in area.

The point frame method we used probably overestimated cover since we recorded all hits by a pin encountered in a path to the soil surface. Cover

by this method could exceed 100 percent for any one plot. An advantage, however, is that it provides cover values for all species in a stratified shrub/grass/forb community.

*Figure 8.--The Abies/ Calamagrostis/Arnica community.*

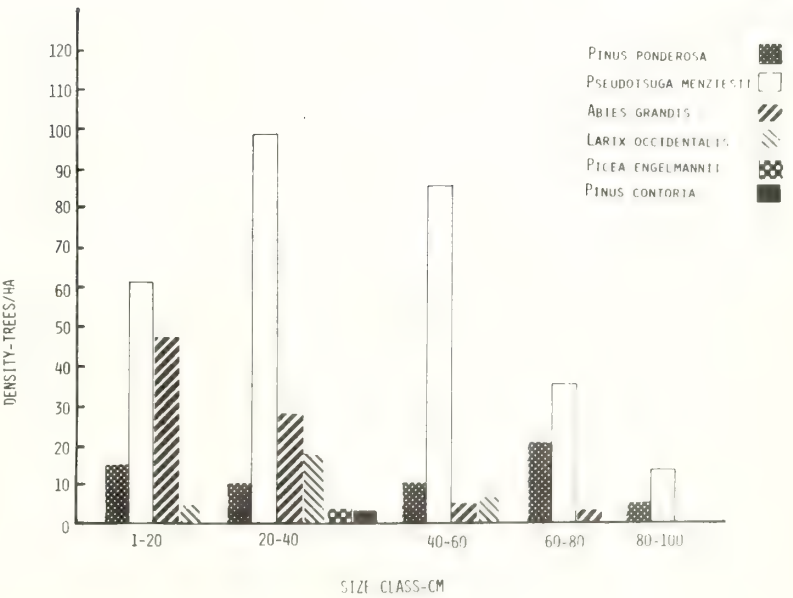


*Figure 9.--Density of tree species by size class in the Abies/ Calamagrostis/Arnica community.*

## SOILS

As pointed out earlier, our first sample occasion showed that each of the major soil associations found on Meeks Table support different plant communities. The *Artemisia/Poa/Eriogonum* and *Artemisia/Poa/Sedum* plant communities occupy the shallow rockland association which can be separated into two subassociations, S1A and S1B, respectively. The *Artemisia/Stipa/Phlox* and the *Pinus/Calamagrostis/Lupinus* plant communities are found on soil association S2 characterized by "biscuit-swale" microtopography, hereafter referred to as subassociations S2A and S2B, respectively. The *Abies/Calamagrostis/Arnica* community is found on association S3 characterized by a rather uniform moderate depth of volcanic ash.

Recent geologic history and climate have played an important part in the development of these soil associations and the subsequent vegetation composition and cover on Meeks Table. During the Miocene epoch, the table was formed by extrusive Yakima basalt flows apparently associated with the formation of the Columbia Plateau. From a soil formation standpoint, the plateau basalts are significant since the basaltic rock has quite different chemical and physical properties than granitic and other kinds of felsic rock that more typically make up the continental surface. Maific mineral constituents of basalt produce distinctive soils rich in calcium, magnesium, and iron.

During the late Salmon Springs stage of the Wisconsinan age of glaciation earlier than 10,000 to 18,000 years B.P. (Crandell and Miller 1974), the non-glaciated upper slopes of the east Cascades, including Meeks Table, appear to have been under the influence of mesic subalpine climatic conditions. Most likely, geologic denudation was very active during this period. However, soil profile examination gives evidence that small areas of soil developed earlier or during this time of subalpine climatic conditions resisted complete denudation on Meeks Table. These soil remnants are found as compact, fine-textured gley material in immediate contact with the basalt parent material.

Following the last stage of glaciation, considerable volcanic activity covered the east Cascade slopes with layers of volcanic ash and pumice. Most of the present surface microtopography of Meeks Table appears to be the result of aeolian deposition of volcanic ash. Although the primary source has not been positively identified by geochemical or petrological analyses, the ash appears to be predominantly Mount Rainier layer R, O, and C composition (Mullineaux 1974). Most of the present volcanic ash surface is covered 0.5 to 5 cm deep with the grey to white layer T or post T ash from Mount St. Helens (Okazaki 1972).

Depth and location of the present volcanic ash layer appears to be a result of wind currents and soil remnants spared by earlier denudation. Essentially no volcanic ash is present nor do we find earlier soil remnants on the wind-swept south and north rims occupied by the *Artemisia/Poa/Eriogonum* and the *Artemisia/Poa/Sedum* communities. These two plant communities are found on the same shallow rockland soil subassociations, S1A and S1B. Differences in plant cover and composition reflect differences in texture, depth, rock cover, and available moisture between the rim land on the windward side of the table as compared with the leeward side. Upslope drainage also adds to the moisture availability for the *Artemisia/Poa/Sedum* community.

The *Artemisia/Stipa/Phlox* and the *Pinus/Calamagrostis/Lupinus* communities are found on the soil association S2A and S2B characterized by "biscuit-swale" microtopography. Here the "biscuit" areas are dunes of volcanic ash and the

"swale" areas are easily recognized by their rock content in the weathered basalt residuum surface. Subassociation S2B is distinguished from S2A by a significantly greater proportion of the land surface covered with dunes (biscuits) than swales. The S2A subassociation has only scattered dune areas.

The residuum surface is continuous under the volcanic ash dunes which range from a few to near 60 cm deep. Under some part of the larger dunes, however, most often the southwest side, a gritty gley material with a strongly developed blocky structure is situated between the residuum and the volcanic ash. Volcanic dune position appears to be closely related to the presence or absence of the gley material.

The plant communities found on soil subassociations S2A and S2B appear to reflect the frequency of the volcanic dunes. Although both *Pinus/Calamagrostis/Lupinus* and *Artemisia/Stipa/Phlox* communities have developed under summer drought conditions, adequate soil moisture appears to be available to support a forest community only in the area with more frequent dunes. Soil moisture utilization by the present forest community on subassociation S2B, however, appears to be sufficient to restrict conifer regeneration in this area as indicated by the sparse tree density in the 1- to 20-cm size class. The dense understory of *C. rubescens* and *C. geyeri* and the deep litter mat are factors that further limit regeneration in the *Pinus/Calamagrostis/Lupinus* community because of competition for moisture and lack of a suitable seedbed. Overland water flow during spring snowmelt has been observed in the area occupied by the *Artemisia/Stipa/Phlox* community and small drainage patterns are developing. Evidence of overland flow has not been observed elsewhere on the table.

Soil association S3 supporting the *Abies/Calamagrostis/Arnica* community is generally characterized by a continuous volcanic ash layer 30- to 60-cm over a 10- to 30-cm gley layer, on top of the basalt residuum. It appears that soil moisture retention of this soil association is sufficient to support the plant community requiring more mesic conditions (Daubenmire 1968) than any of the other communities located on the table. With the exception of snow deposition differences due to wind patterns and interception, precipitation should be uniform across the table. Thus, the plant community on each soil association predominantly reflects the capacity of the soil to provide sufficient moisture during the droughty summer months and conform with the factors controlling vegetation patterns as pointed out by Daubenmire (1943).

Differences in soil associations described above are reflected in the soil chemical characteristics as well as their physical properties (table 3). Results of our soil analyses reinforce community distinctions based on similarity analyses of shrubby and herbaceous vegetation.

Of the plant nutrients active in biogeochemical cycling, total nitrogen, carbon, and sulfur levels in the surface 7.5 cm showed the widest spread among soil associations of any constituents studied (table 3). Total soil nitrogen was lowest in the S1A association (0.06 percent) and highest in the S2B association (0.19 percent). Total N increased significantly ($P = 0.05$) in the order S1A < S3 < S1B = S2A < S2B. The surface 7.5 cm of soil in the S2B association contained six times more total organic carbon (3.4 percent) than the S1A association (0.5 percent). Total organic carbon was significantly different ($P = 0.05$) among all communities. Both total nitrogen and total carbon values declined with depth.

Total sulfur in the surface 7.5 cm was the same in S1A and S3 (0.010 percent) but significantly lower than the other three soil associations. Total sulfur in S2A was significantly higher ($P = 0.05$) (0.019 percent) than in S2B (0.016) but

Table 3--*Summary of soil characteristics, Meeks Table*[1/]

| Constituent or characteristic | Depth (cm) | Soil Association and Community | | | | |
|---|---|---|---|---|---|---|
| | | S1A *(Artemisia/ Poa/ Eriogonum)* | S1B *(Artemisia/ Poa/ Sedum)* | S2A *(Artemisia/ Stipa/ Phlox)* | S2B *(Pinus/ Calamagrostis/ Lupinus)* | S3 *(Abies/ Calamagrostis/ Arnica)* |
| Percent total nitrogen | 0-7.5 | 0.06[a] | 0.13[b] | 0.14[b] | 0.19[d] | 0.11[c] |
| | 15-22.5 | | | 0.13 | 0.15 | 0.09 |
| | 30.5-38 | | | | 0.12 | 0.07 |
| Percent total carbon | 0-7.5 | 0.5[a] | 1.5[b] | 1.7[c] | 3.4[d] | 2.4[e] |
| | 15-22.5 | | | 1.3 | 2.8 | 1.8 |
| | 30.5-38 | | | | 2.2 | 1.4 |
| Percent total sulfur | 0-7.5 | 0.010[a] | 0.017[bc] | 0.019[b] | 0.016[c] | 0.010[a] |
| | 15-22.5 | | | 0.021 | 0.016 | 0.011 |
| | 30.5-38 | | | | 0.018 | 0.012 |
| pH | 0-7.5 | 6.28[a] | 5.76[b] | 5.86[b] | 5.47[c] | 5.77[b] |
| | 15-22.5 | | | 5.67 | 5.61 | 5.66 |
| | 30.5-38 | | | | 5.68 | 5.57 |
| Cation exch. cap. me/100 g | 0-7.5 | 14.5[a] | 16.1[a] | 20.9[b] | 27.6[c] | 22.6[bc] |
| | 15-22.5 | | | 23.2 | 29.0 | 24.8 |
| | 30.5-38 | | | | 31.4 | 26.8 |
| Exchangeable Na me/100 g | 0-7.5 | 0.127[a] | 0.131[a] | 0.139[a] | 0.127[a] | 0.103[b] |
| | 15-22.5 | | | 0.155 | 0.130 | 0.123 |
| | 30.5-38 | | | | 0.149 | 0.131 |
| Exchangeable Ca me/100 g | 0-7.5 | 4.70[a] | 5.17[a] | 5.78[a] | 5.74[a] | 5.84[a] |
| | 15-22.5 | | | 6.49 | 6.33 | 6.71 |
| | 30.5-38 | | | | 6.60 | 6.41 |
| Exchangeable Mg me/100 g | 0-7.5 | 1.36[a] | 1.01[b] | 1.34[a] | 1.26[a] | 0.94[b] |
| | 15-22.5 | | | 1.61 | 1.42 | 1.47 |
| | 30.5-38 | | | | 1.68 | 1.83 |
| Exchangeable K me/100 g | 0-7.5 | 0.41[a] | 0.46[a] | 0.51[a] | 0.94[b] | 0.89[b] |
| | 15-22.5 | | | 0.43 | 0.92 | 0.77 |
| | 30.5-38 | | | | 0.76 | 0.69 |
| Bulk density $g/cm^3$ | 0-7.5 | 1.5[a] | 1.4[a] | 1.3[b] | 1.0[c] | 0.9[d] |
| | 15-22.5 | | | 1.2 | 0.9 | 0.9 |
| | 30.5-38 | | | | 1.0 | 0.9 |
| Percent sand | 0-7.5 | 50.5[a] | 50.8[a] | 46.6[ab] | 41.3[c] | 43.8[bc] |
| | 15-22.5 | | | 44.5 | 36.2 | 40.1 |
| | 30.5-38 | | | | 37.7 | 35.5 |
| Percent silt | 0-7.5 | 38.5[ab] | 34.6[b] | 35.1[b] | 39.3[a] | 41.8[a] |
| | 15-22.5 | | | 35.6 | 41.8 | 41.8 |
| | 30.5-38 | | | | 39.8 | 41.9 |
| Percent clay | 0-7.5 | 11.0[a] | 14.6[b] | 18.5[c] | 19.4[c] | 14.4[b] |
| | 15-22.5 | | | 19.9 | 22.0 | 18.1 |
| | 30.5-38 | | | | 22.5 | 22.6 |
| Percent available soil moisture 0.1 to 15 bars | 0-7.5 | | | 11[a] | 14[b] | 13[ab] |
| | 15-22.5 | | | | 15 | 11 |
| | 30.5-38 | | | | 13 | 12 |

[1/] Values for communities with the same superscript letter are not significantly different at P = 0.05.

there were no significant differences in total sulfur between either of these and S1B. Total sulfur values, in contrast to those of total nitrogen and carbon, increased with depth.

Hydrogen ion activity (pH) of the surface 7.5 cm was significantly higher in the S1A association than any other soil association. This may be an anomalous measurement since the base saturation level for S1A is lower than the other soil associations.

Concentrations of calcium ranged from 4.7 to 5.8 me/100 g in the surface 7.5 cm of soil. Although there were some significant differences among soil associations supporting different plant communities for exchangeable magnesium and sodium, differences are probably not great enough to isolate one community from another on this basis alone. Exchangeable potassium in the surface 7.5 cm was, however, approximately twice as great in the soil association supporting the forested communities as those associations supporting the shrub-grass communities. Exchangeable potassium decreased with depth whereas concentrations of calcium, magnesium, and sodium increased.

We do not have data on total potassium concentration or the distribution of potassium in the litter layer which could help determine the reason for the difference in exchangeable potassium between forested and shrub-grass-covered soil associations. It appears that organic matter may influence this difference since exchangeable potassium trends follow those of organic carbon. Differences in soil depth and area of soil exploration by roots of different plant species may be other contributing factors.

Bulk density was closely related to the presence or absence of volcanic ash. Thus, the ash-free soils of association S1 had a density range of 1.4 to 1.5 grams per cubic centimeter while the predominantly volcanic ash soils of association S3 were about 0.9 grams per cubic centimeter. Soil texture was also influenced by the presence or absence of predominantly silt and fine sand-size volcanic ash. Soil moisture retention characteristics for each sampled depth were highly influenced by the organic matter content as well as the volcanic ash content of each association. Available soil moisture may be a misleading parameter for an assessment of the total moisture available for plant growth in S2B and S3 soils. Available soil moisture in the upper 38 cm was the same in both soils (table 3). Because of the undulating dunes resulting in a "biscuit-swale" formation, however, we conclude that there is less total volcanic ash (soil) in S2B than S3 and therefore a lower total moisture capacity for the community.

The total capital of soil nutrients also governs the potential development of vegetation on a particular soil association. The capital (kg/ha) of nutrients in the measured profile of each soil association and subassociation are presented in table 3. Total capital of nitrogen and sulfur increased in the following order of soil associations and subassociations: S1A < S1B < S3 < S2A < S2B (table 4). For nitrogen and sulfur, this order follows the apparent productivity of the various associations except association S3. A possible higher percentage of the total site nutrient capital in the biomass and litter of the *Abies/Calamagrostis/Arnica* community than in other plant communities may account for this difference.

Capitals of exchangeable Ca, Mg, and Na in S1A and S1B were similar, but only 20 to 30 percent of the amounts found in S2A, S2B, and S3. Exchangeable K capital reflected the differences in concentration among communities--S1A and S1B (180 and 189 kg/ha) and in S2B and S3 (1 048 and 1 211 kg/ha), but intermediate in S2A (576 kg/ha).

Table 4--*Total capital of nutrient constituents in soil of Meeks Table*

| Constituent | Soil association and community | | | | |
|---|---|---|---|---|---|
| | S1A (depth, 7.5 cm), *Artemisia/ Poa/ Eriogonum* | S1B (depth, 7.5 cm), *Artemisia/ Poa/ Sedum* | S2A (depth, 22.5 cm), *Artemisia/ Stipa/ Phlox* | S2B (depth, 38.0 cm), *Pinus/ Calamagrostis/ Lupinus* | S3 (depth, 38.0 cm), *Abies/ Calamagrostis/ Arnica* |
| | kg/ha | | | | |
| Organic carbon | 5,625 | 15,750 | 47,250 | 99,316 | 63,954 |
| Total nitrogen | 675 | 1,365 | 4,252 | 5,439 | 3,078 |
| Total sulfur | 113 | 178 | 614 | 591 | 338 |
| Exchangeable Ca | 1,322 | 1,088 | 3,872 | 4,426 | 4,334 |
| Exchangeable Mg | 185 | 128 | 563 | 624 | 586 |
| Exchangeable K | 180 | 189 | 579 | 1,211 | 1,048 |
| Exchangeable Na | 33 | 32 | 106 | 110 | 94 |

## Conclusions

The array of vegetation communities observed on Meeks Table appears to be a successional response to soil formation and climatic factors. Each community appears to be near equilibrium with the dominant controlling factor, in this case soil moisture availability during the summer months. Subsequent successional stages are not immediately anticipated until there is significant stand structure alteration by fire, insects, or forest management.

Forest management alternatives which influence soil moisture relations will have an important effect on the composition of future plant communities including natural conifer regeneration on this table or other areas in the interior Pacific Northwest that have developed in a similar manner.

Information on soil nutrient levels for the east Cascades is sparse and there appears to be no characterization for any single community (or habitat type) throughout its range. Extension of information from one area such as Meeks Table to other areas should therefore be made with some caution.

Nitrogen levels in the *Pinus* community correspond to Jenny's (1930) value for 5°C MAT in a forested region whereas total N in the *Abies* community was substantially lower than Jenny's values. Our results for total N correspond closely to those reported by Geist and Strickler (1970) for similar soils and vegetation communities of the Starkey Experimental Range in eastern Oregon.

High levels of N in the *Pinus/Calamagrostis/Lupinus* community may be an indication that *Lupinus laxiflorus* plays an important role in the nitrogen economy of these plant communities. Alexander (1961) lists *Lupinus* as one of the more vigorous nitrogen fixers and cites values of N fixation in excess of 100 kg/ha/year under farm conditions with well nodulated roots and favorable meteorological conditions. Fixation rates, however, in wildland situations such as Meeks Table are probably much lower.

The importance of sulfur as a major nutrient in wildland soils has not been emphasized until recently. Tiedemann (1972) and Klock et al. (1971) have found sulfur to be limiting in both amount and availability on soils derived from ash, basalt, and mixtures of ash, pumice and granitic materials. Most total sulfur levels observed to date are at the lower end of the range reported for the United States of 0.01 to 0.06 percent (Burns 1968). Soils of Meeks Table are no exception.

The ratio of carbon to nitrogen to sulfur (C:N:S) was favorable in the three shrub-grass communities, varying from 48:5:1 to 96:8:1. In the forested communities, however, the ratio was 214:12:1 and 230:10:1 for *Abies* and *Pinus* communities, respectively. The high ratio of C:N is not uncommon in forested communities of the east Cascades (Anderson and Tiedemann 1970; Tiedemann 1972; and Geist and Strickler 1970). The C:N ratios, however, are in the critical range given by Black (1968) of 15:1 to 33:1. By this standard, which was developed for agricultural soils, high C:N ratios would affect N availability in the two forested communities of Meeks Table. The N:S ratio was in the range for optimal utilization of N by plants in all Meeks Table communities. Burns (1968) concludes that the favorable ratio for N:S is 10:1. The ratio is probably meaningless in the *Artemisia/Poa/Eriogonum* community because of the very low nitrogen and sulfur levels.

These results suggest a need to study the relationships among soil nutrient levels, soil nutrient availability, and biomass production for forest and range sites of the east Cascades. This information, along with information on soil moisture availability, is basic to an understanding of the effects of land use practices on future site productivity.

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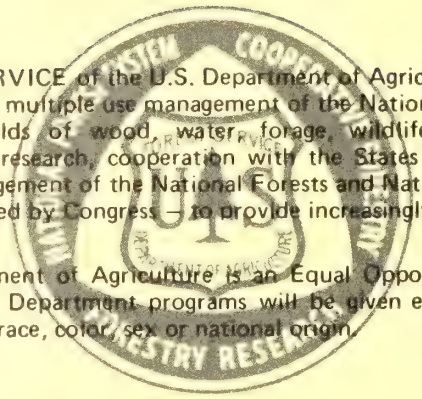

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# IMPACT OF THE DOUGLAS-FIR TUSSOCK MOTH IN FOREST RECREATION IN THE BLUE MOUNTAINS

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BLISHED IN COOPERATION WITH THE
DA DOUGLAS FIR TUSSOCK MOTH
OGRAM

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# IMPACT OF THE DOUGLAS-FIR TUSSOCK MOTH ON FOREST RECREATION IN THE BLUE MOUNTAINS

*Reference Abstract*

Downing, Kent B., Phillip B. Delucchi, and William R. Williams. 1977. Impact of the Douglas-fir tussock moth on forest recreation in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-224, 14 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of recreationists, resort owners, packer-guides, motel operators, and employees of natural resource agencies revealed little evidence that a recent outbreak of Douglas-fir tussock moth had significant or widespread influence on recreation in northeastern Oregon.

KEYWORDS: Douglas-fir tussock moth, *Orgyia pseudotsugata*, recreation, recreation use, insects, insect damage (-forest, Oregon (Blue Mountains), Oregon (northeastern), Blue Mountains--Oregon, northeastern Oregon.

*RESEARCH SUMMARY*

*Research Paper PNW-224*

*1977*

In this paper, we report impacts of a recent Douglas-fir tussock moth outbreak and subsequent DDT control program on recreationists and private recreation businesses in northeastern Oregon. The decision to apply DDT in 1974 generated considerable controversy that received widespread national as well as local and regional news coverage.

Data were collected in 1975 by on-site interviews with summer recreationists and deer and elk hunters, telephone interviews with persons who had hunted in northeastern Oregon during 1971, 1972, or 1973, owners of private recreation businesses, and personnel with public land-management agencies.

Although the land-management agencies reported numerous inquiries about the tussock moth during the peak of the controversy in 1973 and 1974 and a large proportion of recreationists interviewed had heard about the situation, we found little evidence that the damage or spraying affected recreation businesses or caused any appreciable reduction in recreational participation. Estimates of the short-term impact on recreationists appear to have been exaggerated.

Efforts to inform the public about the tussock moth seem to have been effective and undoubtedly aided interested citizens to obtain additional information if they wanted it. Once the decision to spray had been made and the control program completed, however, the intensity of public interest declined rapidly. The tussock moth and spray program apparently were no longer salient to most recreationists in 1975.

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# Introduction

An outbreak of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), in eastern Washington, northeastern Oregon, and northern Idaho caused various degrees of damage to trees on 800,000 acres (324 000 ha) over a 4-year period and culminated in a control program of aerial application of DDT (dichlorodiphenyltrichloroethane) in 1974.[1/]

The entire tussock moth issue received national as well as local and regional attention as a result of the controversy generated by the decision to spray with DDT. Although more than 90 percent of the written comments[2/] from persons living in noninfested as well as infested areas of Washington and Oregon supported the application of DDT to control tussock moth, various wildlife and environmental organizations opposed its use.

Benefits from insect control programs should exceed costs incurred in the control effort. But benefits of protecting scenic and recreational resources are difficult to measure in dollars. Furthermore, because some defoliation and tree mortality occur naturally in forests, defining what forest visitors consider unacceptable damage is difficult.[3/]

To influence patterns of recreational behavior, events occurring in the damaged areas had to be perceived by recreationists as likely to interfere with a safe or pleasurable outing. Four distinct factors associated with the tussock moth outbreak, and subsequent management activities could have affected experiences of on-site visitors or influenced others to visit or avoid damaged areas.

- *The presence of insects--especially larvae.* The insects fall on visitors or get into food or clothing, and some persons are allergic to hairs of the tussock moth larvae.

- *Discoloration, defoliation, and mortality of forest vegetation.* The immediate consequence is a change in the appearance of the landscape. In the long run, the potential for physical hazard to forest visitors from falling limbs or fire is increased.

- *Intensified management activities.* DDT spraying, salvage logging, road building, and heavy equipment activity along forest roads may have inconvenienced some visitors and probably increased the chance for accidents along some logging roads, particularly on weekdays. Probably the greatest impact of road construction has been to change recreation

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1/ Graham, David A., Jack Mounts, and Dewey Almas. 1974. Cooperative Douglas-fir tussock moth control project. USDA Forest Service. Pacific Northwest Region. Portland. 74 p.

2/ Kelley, Stephen A., and William J. Rompa. 1973. Public opinions about controlling the 1973 Douglas-fir tussock moth outbreak. USDA Forest Service. Pacific Northwest Region. Portland. 27 p.

3/ USDA Forest Service. 1974. Forest Service-USDA environmental statement, cooperative Douglas-fir tussock moth pest management plan. Pacific Northwest Region. Portland. 355 p.

opportunities for the forest visitor; remote areas, previously accessible only on foot or horseback, can now be entered by automobile or snowmobile.

- *Flow of information about the tussock moth and control measures.* News stories and information passed along by persons who had been in the area may have altered visitors' expectations or influenced their decision to visit damaged areas. For example, news releases in 1974 warned hunters about DDT residues in the fat tissues of game animals.

The tussock moth outbreak and control also might affect public and private organizations such as resorts, motels, and recreation management agencies that supply recreation services. Furthermore, any significant changes in patterns of recreational use would be felt in the economy of nearby communities.

We describe effects of the tussock moth outbreak, DDT spray program, and salvage logging on recreational visitors and on organizations that serve recreationists in four counties of northeastern Oregon. We sought to understand and to measure human response to epidemics of defoliating forest insects.

## Methods

Our investigation began in the summer of 1975, 1 year after DDT was sprayed. We began the study on the assumption that the impact of tussock moth and related control actions should still be detectable even though the most immediate and direct influences occurred earlier--in 1973 and 1974, when insect populations were at their peak and the proposed DDT spray program was generating much public interest. To overcome this time-lag problem and to insure that the study would produce an accurate description of how people responded to the outbreak and control action, we collected data from diverse sources by a variety of survey methods.

*On-site visitors summer and fall, 1975.* Summer recreationists, deer hunters, and elk hunters were interviewed from August through November. Visitors were interviewed at two State parks and at selected campsites and forest roads in the Umatilla and Wallowa-Whitman National Forests. Through a planned sequence of questioning, recreationists were asked: (1) if they had noticed any changes in the Blue Mountains recently; (2) if they had changed their recreation patterns in response to gasoline shortages, economic conditions, declining deer populations, or insect problems; and finally, (3) if they were aware of problems in the area with the Douglas-fir tussock moth or mountain pine beetle.

*Previous recreational visitors.* The only link that could be established with recreationists who may have avoided damaged areas in 1975 because of the tussock moth--persons who would not be included during the on-site interviewing--was through special elk season hunting lists from the Oregon State Wildlife Commission. Hunters who had special elk permits in 1971, 1972, and 1973, were asked, by telephone, a sequence of questions similar to that in the on-site interviews.

*Private firms that supply recreation services.* Operators of packing and guide services and resorts in the area, by personal interview and a random sample of motel owners by mailed questionnaire, were asked:

(1) if during recent years customers asked about the availability of gasoline, declining deer populations, mountain pine beetle, or the tussock moth situation; (2) if the operators believed gasoline shortages, declining deer populations, economic conditions, mountain pine beetle, or the tussock moth situation had any impact on their businesses; and (3) if the firms changed their mode or location of operation in response to tussock moth damage in areas important to their businesses.

Owners were also asked to provide data on business volume for 1970-75 comparison with other data collected from public agencies.

*Statistics on recreational use from public agencies.* Reliable recreational use data for 1970-75 were collected from the Oregon State Parks Department. Forest Service data were incomplete and could not be used because funding for double sampling visits at recreation sites was reduced significantly in Region 6 after 1973.

*Interviews with public agency staff.* Staff with public agencies such as the Oregon State Parks Branch of the Department of Transportation, U.S. Forest Service, and the Oregon Wildlife Commission were asked to recall the nature and amount of citizen inquiry--by letter, phone, or office visit--that concerned the tussock moth. They were also asked about the extent and cost of cleanup required on recreation sites as a result of tussock moth damage.

## Results

### ON-SITE VISITOR SURVEY

Field interviews were completed with 780 persons under the following conditions:

| | Respondents (Percent) |
|---|---|
| Interview season | |
| Summer (Aug. 1-28) | 53 |
| Deer season (Oct. 1-9) | 21 |
| Elk season (Nov. 1-11) | 26 |
| Interview location | |
| State parks | 15 |
| Forest Service campgrounds | 36 |
| Along Forest Service roads | 49 |
| Time of interview | |
| Weekend | 60 |
| Weekday | 40 |

Characteristics of respondents varied considerably:

| | |
|---|---|
| Age (Years) | |
| 15-30 | 23 |
| 31-60 | 67 |
| Over 60 | 10 |

| Size of party (Persons) | Respondents (Percent) |
|---|---|
| 1 | 8 |
| 2 | 31 |
| 3-7 | 50 |
| 8 or more | 11 |
| **Composition of party** | |
| Alone | 8 |
| Families with children | 37 |
| Groups (2 or more) | 51 |
| Other | 4 |
| **Residence** | |
| Local[4/] | 55 |
| W. Oregon | 28 |
| E. Oregon | 4 |
| W. Washington | 1 |
| E. Washington | 4 |
| Other | 8 |
| **Familiarity with the area** | |
| First-time visitors | 18 |
| Repeat visitors | 82 |
| **Prior visits to other Blue Mountain areas** (Number of areas) | |
| 0 | 18 |
| 1-2 | 41 |
| 3-5 | 13 |
| 5 | 28 |

Nearly 60 percent of the respondents lived nearby or in other eastern Oregon locations. Eight of 10 had been to the interview site before and had visited other areas of the Blue Mountains as well.

Of the 640 repeat visitors, 73 percent had visited areas where the tussock moth was active during 1972-74 and 45 percent had been in the area before 1972.

*Awareness of tussock moth: No direct questions.* First-time visitors (N = 115) were asked if any aspects of the Blue Mountains had not lived up to their expectations and if they had read--or heard people talk about--changes in the Blue Mountains. Respondents mentioned road problems, seeing too many people, and changes in recreation sites and facilities. Only two persons (2 percent) mentioned the Douglas-fir tussock moth.

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[4/] Includes these counties: Idaho - Lewis, NezPerce, Payette, Washington; Oregon - Baker, Umatilla, Union, Wallowa; Washington - Asotin, Columbia, Garfield, Walla Walla.

Repeat visitors (N = 640) were asked if they had noticed any major changes since they had been coming to the Blue Mountains. Eighty percent said they had observed changes, as follows:

| Changes mentioned | Directly observed changes | Read or heard about changes | Total |
|---|---|---|---|
| | (Percent) | (Percent) | (Percent) |
| Roads | 38 | 2 | 40 |
| Campsite and facilities | 34 | 3 | 37 |
| People in the area | 22 | 1 | 23 |
| Tussock moth | 7 | 2 | 9 |
| Other insects | 1 | <1 | 1 |
| Other | 16 | 2 | 18 |

Overall, without any direct probing about insect problems or tussock moth, 9 percent of the repeat visitors (N = 640) said that they had directly observed or read or heard about changes in the Blue Mountains they thought were caused by the Douglas-fir tussock moth.

All of the respondents (N = 780) were asked if changes or events over the last 2 or 3 years had influenced their decision to visit the Blue Mountains. Twenty-nine percent said yes:

| Change or event | Respondents | |
|---|---|---|
| | (Percent) | |
| Roads | 2 | |
| Campsites and recreation facilities | 2 | |
| Gasoline (price or availability) | 1 | |
| People in the area | 1 | |
| Douglas-fir tussock moth | 1 | (7 people) |
| Various other comments | 22 | |
| No influence | 71 | |

Of the seven who changed plans because of the tussock moth, one went to a different area in the Blue Mountains, another cancelled the trip, and one was said to have become sick because of dust from the logging of moth-killed trees. The other four did not specifically explain how their plans changed.

*Awareness of tussock moth: Direct questions.* After indirect questioning, the interviewers asked if gasoline shortages, inflation in the economy, or insect problems in the Blue Mountains affected respondents' recreational activities. Of the 697 people who were asked the question, 208 mentioned the tussock moth and 30 said they stayed out of the area because of it. The other responses related to the tussock moth concerned visual changes, DDT spraying (no one reported avoiding areas sprayed with DDT), and skin irritations.

On August 13, halfway through the summer interview period, the questionnaire was modified so that after the indirect questioning about insects, the interviewer asked the respondents directly if they had heard of the tussock moth situation. Table 1 summarizes the awareness of different groups of the respondents.

Table 1--*Awareness of the tussock moth situation by persons interviewed after August 12*

| Item | Sample size | Knowledge of tussock moth | | | |
|---|---|---|---|---|---|
| | | Without direct questions | When asked about insect problems | When asked about tussock moth | No knowledge of tussock moth |
| | Number | Percent | | | |
| Category of visitor | | | | | |
| All respondents | 580 | 9 | 26 | 49 | 16 |
| First-time | 65 | 2 | 20 | 46 | 32 |
| Repeat | 515 | 10 | 26 | 50 | 14 |
| Summer | 212 | 10 | 45 | 15 | 30 |
| Deer season | 162 | 9 | 13 | 69 | 9 |
| Elk season | 206 | 7 | 16 | 71 | 6 |
| Activity | | | | | |
| Hunting | 305 | 6 | 14 | 72 | 8 |
| Gathering forest products | 87 | 13 | 32 | 38 | 17 |
| Fishing | 79 | 15 | 29 | 33 | 23 |
| Hiking | 74 | 12 | 22 | 50 | 16 |
| General | 240 | 7 | 28 | 46 | 19 |
| Friends | 13 | 8 | 31 | 46 | 15 |
| Travel | 79 | 9 | 38 | 34 | 19 |
| Sports | 42 | 7 | 31 | 41 | 21 |
| Others | 62 | 10 | 24 | 55 | 11 |
| Residence | | | | | |
| Local | 305 | 10 | 31 | 43 | 16 |
| Oregon (other than local) | 219 | 7 | 16 | 67 | 10 |
| Washington | 26 | 4 | 31 | 34 | 31 |
| Other (all other States) | 27 | 7 | 41 | 15 | 37 |
| Avoided infested areas | 580 | <1 | 4 | 2 | -- |

Overall, less than 1 person in 10 mentioned tussock moth problems when questioned about changes in the area or events that influenced recreational travel plans in the Blue Mountains. When asked specifically about the tussock moth, 16 percent of the respondents said they were not aware of problems in the area. The percentages for all respondents combined can be misleading, however; differences in awareness by season of interview and by characteristics of respondents are important.5/

Thirty percent of the summer visitors were unaware of the tussock moth situation--a much greater proportion than deer and elk season visitors (9 and 6 percent, respectively).

A higher proportion of fishermen, hikers, and gatherers of forest products such as berries mentioned the tussock moth before direct probing by interviewers. A higher proportion of those in the "Others" activities category--mostly workers in the area--as well as deer and elk hunters, mentioned tussock moth as the result of direct probing. Only 10 percent of the local visitors mentioned tussock moth before direct questions about insects or the tussock moth.

Although the tussock moth related events of 1972, 1973, and 1974 generated considerable controversy locally as well as elsewhere in the Northwest, these events apparently were no longer salient to most on-site visitors interviewed in 1975.

*Impact of the tussock moth on recreation activity.* With the questionnaire as modified after August 12, 580 recreationists were interviewed. Less than 1 percent indicated--before directly questioned

5/ Percentages for the degree of awareness of the "All respondents" category varies depending on the proportion of different subgroups in the sample; for example, the proportion of summer visitors to deer- and elk- season visitors.

about it by the interviewer--that they had stayed away from tussock moth areas. Four percent said they avoided the tussock moth when the interviewer asked about insect problems. Of those asked specifically about tussock moth, only 2 percent said they avoided damaged areas. We could not determine if visitors stayed away because the moth was active or because areas had been sprayed with DDT.

## *TELEPHONE SURVEY*

A disproportionate stratified sample of special elk season permits for 1971, 1972, and 1973 was selected; and the hunters were telephoned:

| Residence | Permits on 1971-73 lists | | Hunters interviewed | |
|---|---|---|---|---|
| | (Number) | (Percent) | (Number) | (Percent) |
| Local | 82 | 10 | 33 | 29 |
| E. Oregon | 188 | 24 | 39 | 34 |
| W. Oregon | 514 | 66 | 42 | 37 |
| | 784 | 100 | 114 | 100 |

Ninety-six percent of those telephoned had hunted in the Blue Mountains before 1973. No significant differences by home location were found. Proportionately more local respondents, however, hunted and participated in other recreation activities in the area in 1973 or 1974:

| Residence | Respondents | Recreation in 1973 or 1974 | |
|---|---|---|---|
| | | Hunting | Other |
| | (Number) | (Percent) | (Percent) |
| Local | 33 | 94 | 82 |
| E. Oregon | 39 | 77 | 46 |
| W. Oregon | 42 | 71 | 36 |

Respondents were asked two questions to probe for their awareness of the tussock moth situation: (1) had they personally noticed any changes or problems and (2) had they read or heard about changes or problems?

| Type of change | Changes observed directly (Total responses, 211) | Changes read or heard about (Total responses, 127) |
|---|---|---|
| | (Percent) | (Percent) |
| People | 22 | 10 |
| Roads | 19 | 16 |
| Game management | 18 | 17 |
| Administration | 10 | 20 |
| Logging | 10 | 14 |
| Road closure | 8 | 14 |
| Tussock moth | 6 | 9 |
| DDT | 3 | -- |
| Scenery | 4 | -- |
| | 100 | 100 |

Significant variation (at the 0.05 level of probability) in the proportion of responses by home location occurred for only one item. Seventeen percent of the western Oregon residents and 18 percent from eastern Oregon mentioned reading or hearing about tussock moth compared with only 3 percent from the local area.

The respondents were asked specifically about factors that may have influenced their decision to avoid the Blue or Wallowa Mountains in recent years:

| Factor | All respondents N = 114 (Percent) | Local N = 33 (Percent) | E. Oregon N = 39 (Percent) | W. Oregon N = 42 (Percent) |
|---|---|---|---|---|
| Game population | 39 | 42 | 38 | 36 |
| Inflation or cost of living | 23 | 30 | 23 | 17 |
| Douglas-fir tussock moth | 18 | 30 | 15 | 10 |
| Gasoline shortages | 15 | 12 | 18 | 17 |
| DDT spraying | 4 | 6 | 3 | 2 |
| Mountain pine beetle | 4 | 9 | 5 | 0 |

Avoidance of areas infested with tussock moth was significantly greater for local residents. Although 23 hunters said the infestation or DDT spraying influenced their decision not to go to the area, 14 (61 percent) did hunt in the Blue or Wallowa Mountains in 1973 and 22 (96 percent) hunted there during 1973 or 1974. Most, however, said they changed hunting locations, presumably to areas with less evidence of damage or where no spraying had occurred.

Based on the 114 hunters sampled, an estimated 15 percent of the 784 hunters who had special elk season permits may have decided not to visit damaged areas because of the infestation or DDT spraying. This compares with about 7 percent of the on-site survey respondents and 5 percent of the on-site elk hunters, who said they avoided areas damaged by tussock moth or sprayed with DDT.

The discrepancy between the on-site interviews and the telephone surveys (particularly between the elk hunting groups) cannot be explained with certainty. However, the question in the telephone survey on factors that may have influenced respondents' decisions to avoid the Blue or Wallowa Mountains at some time was much more specific than the on-site survey questions.

## *SURVEY OF PRIVATE FIRMS*

For information on how tussock moth affected their businesses, we questioned 62 private firms:

| Type | Estimated firms in Northeastern Oregon[6/] | Surveys | Method |
|---|---|---|---|
| | (Number) | (Number) | |
| Packer-guides | 19 | 12 | In person |
| Resorts | 13 | 12 | In person |
| Motels | 65 | 38 | By mail |

*Inquiries about the tussock moth situation.* Operators of the firms were asked if they had received inquiries about the tussock moth situation from their clients. They were also asked about inquiries on game populations, availability of gasoline, and the mountain pine beetle, as well as the DDT spraying and salvage logging associated with the tussock moth outbreak (table 2).

Table 2--*Inquiries to businesses [illegible] influences on [illegible]*

| External factors | Business | Inquiries | | | | | | | | | | Total responses[1/] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Many | | Moderate | | Some | | Few | | None | | |
| | | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number |
| Game population | Resort | 4 | 40 | 2 | 20 | 1 | 10 | 2 | 20 | 1 | 10 | 10 |
| | Packer-guide | 10 | 83 | 2 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| | Motel | 6 | 16 | 7 | 19 | 9 | 24 | 9 | 24 | 6 | 16 | [illegible] |
| Gasoline | Resort | 3 | 30 | 2 | 20 | 3 | 30 | 2 | 20 | 0 | 0 | 10 |
| | Packer-guide | 2 | 17 | 3 | 25 | 2 | 17 | 4 | 33 | 1 | 8 | 12 |
| | Motel | 1 | 3 | 5 | 14 | 7 | 19 | 12 | 32 | 12 | 32 | [illegible] |
| Tussock moth | Resort | 3 | 30 | 2 | 20 | 3 | 30 | 1 | 10 | 1 | 10 | 10 |
| | Packer-guide | 6 | 50 | 2 | 17 | 2 | 17 | 2 | 17 | 0 | 0 | 12 |
| | Motel | 2 | 5 | 0 | 0 | 3 | 8 | 7 | 18 | 26 | 68 | [illegible] |
| DDT | Resort | 1 | 10 | 2 | 20 | 2 | 20 | 2 | 20 | 3 | 30 | 10 |
| | Packer-guide | 5 | 42 | 2 | 17 | 1 | 8 | 3 | 25 | 1 | 8 | 12 |
| | Motel | 3 | 8 | 1 | 3 | 2 | 5 | 6 | 16 | 26 | 68 | [illegible] |
| Mountain pine beetle | Resort | 0 | 0 | 1 | 10 | 2 | 20 | 1 | 10 | 6 | 60 | 10 |
| | Packer-guide | 0 | 0 | 1 | 8 | 1 | 8 | 1 | 8 | 10 | 76 | 13 |
| | Motel | 0 | 0 | 0 | 0 | 1 | 3 | 2 | 6 | 31 | 91 | [illegible] |
| Logging | Resort | 0 | 0 | 0 | 0 | 1 | 11 | 3 | 33 | 5 | 56 | 9 |
| | Packer-guide | 1 | 10 | 1 | 10 | 1 | 10 | 3 | 30 | 4 | 40 | 10 |
| | Motel | 2 | 6 | 4 | 11 | 3 | 8 | 5 | 14 | 23 | 61 | [illegible] |

[1/] Sample size: Resorts 12, packer-guides 12, motels 38. Sum of percentages in each row may not total 100 because of rounding.

Nearly all of the packer-guide and resort operators said they had received inquiries about the tussock moth and DDT spraying. However, just over half reported inquiries about salvage logging. About one-third of the motel operators reported inquiries about tussock moth and DDT spraying.

The operators' views of the impact these activities had on their businesses are summarized (table 3). Overall, many believe game populations and gasoline problems influenced their businesses more than tussock moth, DDT spraying, or logging. One packer-guide cancelled his 1975 operations because salvage logging roads had been built into his usual hunting area. Another believed that personnel associated with the control operations filled local motels so that recreation visitors could not stay in the area to take advantage of his services.

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[6/] Counties include Baker, Umatilla, Union, and Wallowa.

Table 3--[illegible] of firms [illegible] questions about influences on business

| Subject of inquiry | Business | Influences | | | | | | Total responses[1/] |
|---|---|---|---|---|---|---|---|---|
| | | Negative | | Positive | | None | | |
| | | Number | Percent | Number | Percent | Number | Percent | Number |
| Game population | Resort | 4 | 36 | 0 | 0 | 7 | 64 | 11 |
| | Packer-guide | 5 | 42 | 4 | 33 | 3 | 25 | 12 |
| | Motel | 1 | 3 | 20 | 59 | 13 | 38 | 34 |
| Gasoline | Resort | 7 | 70 | 0 | 0 | 3 | 30 | 10 |
| | Packer-guide | 5 | 42 | 0 | 0 | 7 | 58 | 12 |
| | Motel | 9 | 28 | 6 | 19 | 17 | 53 | 32 |
| Tussock moth | Resort | 0 | 0 | 0 | 0 | 10 | 100 | 10 |
| | Packer-guide | 0 | 0 | 0 | 0 | 12 | 100 | 12 |
| | Motel | 2 | 6 | 2 | 6 | 28 | 88 | 32 |
| DDT | Resort | 0 | 0 | 0 | 0 | 11 | 100 | 11 |
| | Packer-guide | 1 | 8 | 0 | 0 | 11 | 92 | 12 |
| | Motel | 2 | 6 | 2 | 6 | 29 | 88 | 33 |
| Mountain pine beetle | Resort | 0 | 0 | 0 | 0 | 11 | 100 | 11 |
| | Packer-guide | 0 | 0 | 0 | 0 | 12 | 100 | 12 |
| | Motel | 1 | 3 | 0 | 0 | 31 | 97 | 32 |
| Logging | Resort | 0 | 0 | 0 | 0 | 11 | 100 | 11 |
| | Packer-guide | 1 | 8 | 0 | 0 | 11 | 92 | 12 |
| | Motel | 0 | 0 | 8 | 25 | 24 | 75 | 32 |

[1/] Sample size: Resorts 12, packer-guides 12, motels 38. Sum of percentages in each row may not total 100 because of rounding.

*Shifts in areas used.* Resort owners and packer-guides were asked if they had shifted areas of primary use because of the tussock moth. Other than the one guide who cancelled his 1975 operations, no shifts in area caused by the tussock moth were reported. Two resorts reported changes because of deer and elk. Five packer-guides reported shifts: one to move closer to home; another to use a wilderness area; and three, within the wilderness area, to avoid concentrations of people.

The operators were also asked if they were aware of any visitors who tried to avoid tussock moth areas (table 4). Two respondents reported that some visitors made a special effort to see tussock moth damage.

Table 4--*Responses by businesses to the question: "Did visitors try to avoid tussock moth areas?"*

| Business | "No" | | "Yes" | | "I don't know" | | Total responses[1/] |
|---|---|---|---|---|---|---|---|
| | Number | Percent | Number | Percent | Number | Percent | Number |
| Resort | 3 | 25 | 1 | 8 | 8 | 67 | 12 |
| Packer-guide | 8 | 67 | 1 | 8 | 3 | 25 | 12 |
| Motel | 11 | 32 | 2 | 6 | 21 | 62 | 34 |

[1/] Sample size: Resorts 12, packer-guides 12, motels 38.

*Changes in business volume.* Adjusted gross income figures for packer-guides and resorts and motel occupancy are shown in figures 1-3. Number of visitors to all Oregon State parks and to northeastern Oregon State parks have been included for comparison. No evidence

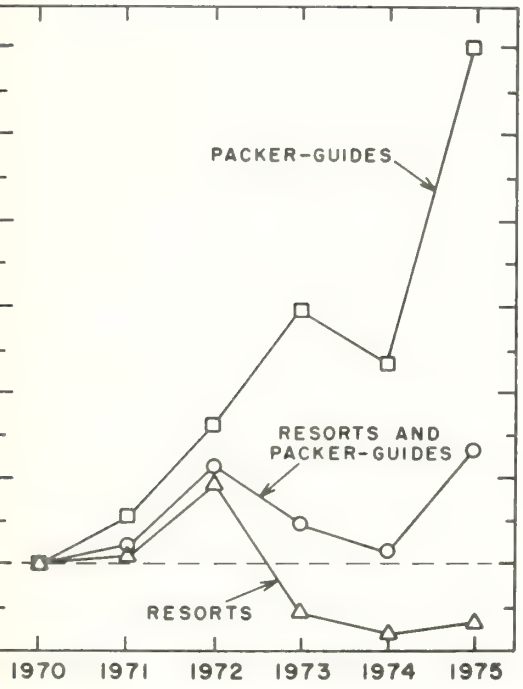


*Figure 1.--Adjusted gross income as a percentage of 1970 gross income for 19 businesses in northeastern Oregon (9 packer-guides and 10 resorts).*

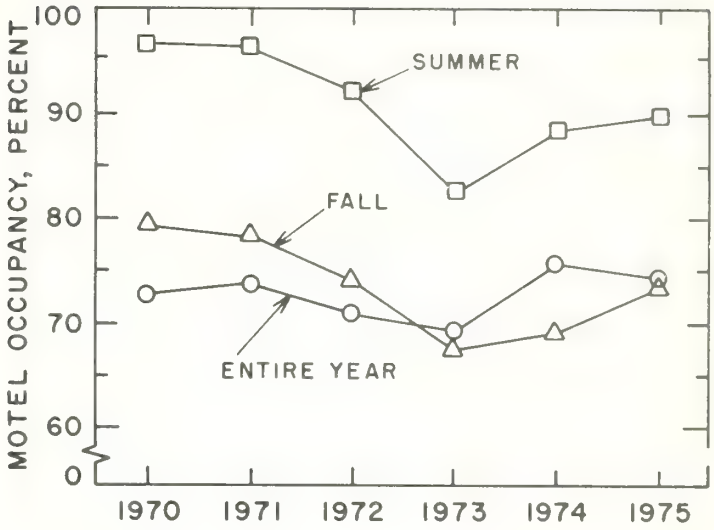


*Figure 2.--Average occupancy for motels in northeastern Oregon.*

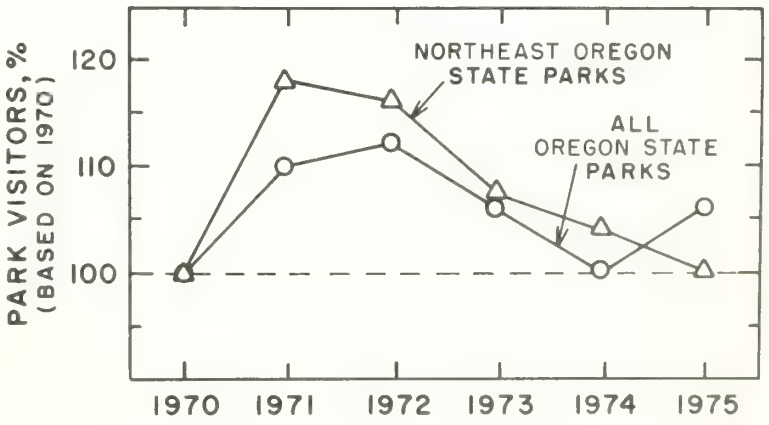


*Figure 3.--Number of visitors to Oregon State parks as a percentage of visitors in 1970.*

indicates that the tussock moth or related events caused any of the business decline coincidental with the tussock moth infestation. Regression analysis using dummy variables to designate the years when the tussock moth was active and to indicate the proximity of the individual businesses to the tussock moth damaged areas did not support the hypothesis that the decrease in visitors or gross income was related to the tussock moth situation.

## *PUBLIC INQUIRY OF MANAGEMENT AGENCIES*

We interviewed 14 employees from U.S. Forest Service Ranger Districts, Oregon State Parks Branch, and an office of the Oregon Department of Fish and Wildlife, working in the area at the time of the outbreak, concerning public inquiries about the tussock moth and related problems.

*Kinds and frequency of questions.* The agencies began receiving inquiries in 1973, although two offices received none until 1974. The most frequent type of contact with the public was a personal visit to the office by those seeking information. We do not know if the visits were specifically for information about the tussock moth or for some other purpose and the tussock moth was of secondary concern. Few inquiries were made by letter. Two Ranger Districts reported as many as two telephone calls a day during the height of the infestation, and the Department of Fish and Wildlife at La Grande estimated about a 100 calls before the spraying and 150 to 200 calls between the end of the spraying and the end of the fall hunting season in 1974. No inquiries were reported in 1975.

Inquiries or concerns voiced by the public are listed below in order of the frequency mentioned to the public employees we interviewed: (1) location of spraying and concern for DDT on mushrooms, berries, and in game animals; (2) concern about avoiding the moth and allergy reactions (primarily by wood gatherers); (3) general concern about the tussock moth situation; and (4) concern about wildlife habitat.

One State park reported telephone calls to ask if the park had been damaged and later to inquire if it had been sprayed.

*Campground cleanup.* Employees of the Forest Service Ranger Districts were asked about the extent of damage to campgrounds and if salvage or removal of dead and damaged trees was necessary. One campground was salvage logged; no other cleanup activities were reported.

The manager of Emigrant Springs State Park and the Blue Mountain Forest Wayside was also called about cleanup activities required because of the tussock moth. The Blue Mountain Forest Wayside was heavily damaged, and the trees were removed for firewood in the State parks. Cost of tree removal was charged to the firewood account, so we could not determine what additional expense was incurred for cleanup after the tussock moth. Emigrant Springs State Park was sprayed twice to prevent tussock moth damage, and it received little.

Emigrant Springs showed a decrease in the number of visitors

beginning in 1972 and reached a low point in 1974; use in 1975 increased slightly. The manager attributed the decline to the completion of a rest area on the interstate highway west of the park; visitors with pickup or trailer campers spent the night in the rest area rather than in the State park. He also believed that the gasoline shortage caused part of the decrease by reducing travel.

## Discussion

A diversity of recreation users and private firms as well as personnel with natural resource agencies were questioned during the surveys. Many of the recreation users had prior knowledge of the tussock moth activity. Only about 7 percent of the on-site respondents, however, said they stayed out of affected areas on recreation trips. This was for only a short period as the visitors were back in the areas in 1975. Fifteen percent of the special elk season hunters avoided infested and sprayed areas (as compared with 5 percent of the elk hunters questioned during the on-site interviews). This discrepancy is likely because of differences in the phrasing of survey questions. On-site responses probably underestimated the short-term avoidance that occurred--particularly for elk hunters.

Private firms, including packer-guides, resorts, and motels, had numerous inquiries about the tussock moth, but only about 4 percent (two motels) thought the moth activity had directly harmed their business volume. One packer-guide did not operate in 1975 because of areas opened by roads.

We found no evidence of widespread reduction in business volume because of the tussock moth, based on an analysis of firms' financial records. In fact, several motel operators believed the infestation, DDT spraying, and logging increased their business, although this could not be directly measured from their records.

## Conclusions

The most significant events of the tussock moth infestation that affected the general public probably occurred: (1) when the insects were actively annoying visitors and discoloring forest vegetation and, (2) when news coverage of the controversy over use of DDT was at its peak in 1973 and 1974. These were intense, yet short-term events that distressed local residents and other concerned citizens and generated considerable confusion and controversy for natural resource managers.

The actual recreation-related dislocations during this period do not appear to be great or widespread. We could find little or no significant relation between moth damage and recreation. At most, a few people, after reading or hearing about annoyances to some recreationists, temporarily shifted their activities to areas where they would not be bothered by the insects or come in contact with DDT residues. We doubt that any significant reduction in the total amount of recreation participation in northeastern Oregon resulted from the tussock moth.

There may be important long-term effects, however. One of the most significant is associated with building roads (or at least accelerating the rate at which roads are built) for salvage logging of damaged timber. This impact on recreation was mentioned by only one packer-guide, although many recreationists--particularly repeat visitors--commented on the road expansion. Road building increases opportunities for those who seek recreation on dispersed roads, but at the expense of those who favor more primitive, backcountry hunting and hiking.

Long-term impacts on recreation, as well as more immediate effects, of natural events like the tussock moth infestation should be included in evaluations of alternative management programs. Where public involvement on the issues will be solicited, potential impacts of this type should be part of the information available to citizens. Clearly, many of those interviewed in this study, including first-time visitors, had some prior knowledge of the tussock moth. Their awareness was influenced not only by their own experiences and information passed on by others, but also by the public information efforts of natural resource agencies.

* * * * *

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1977
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# A TEST OF COMMERCIAL THINNING ON THE HEMLOCK EXPERIMENTAL FOREST

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This paper contains the partial results of a cooperative study by Oregon State University and the U.S. Forest Service.

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# A TEST OF COMMERCIAL THINNING ON THE HEMLOCK EXPERIMENTAL FOREST

## Reference Abstract

Hilt, Donald E., Francis R. Herman, and John F. Bell. 1977. A test of commercial thinning on the Hemlock Experimental Forest. USDA For. Serv. Res. Pap. PNW-225, 11 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

During 11- to 12-year treatment periods, beginning at ages 49 to 55, low and high commercial thinnings, at 3- and 6-year intervals, improved diameter growth of residual trees. Gross merchantable growth per acre apparently was not reduced by thinning. Thinning had no appreciable effect on mortality.

KEYWORDS: Thinning (commercial), commercial thinning, growth response, yield (forest), western hemlock, *Tsuga heterophylla*, Washington (Hemlock Experimental Forest), Hemlock Experimental Forest--Washington.

## RESEARCH SUMMARY

Research Paper PNW-225

1977

Commercial thinnings in a 50-year-old stand of pure, well-stocked, even-aged western hemlock (*Tsuga heterophylla*, Raf.) Sarg.) on the Hemlock Experimental Forest near Hoquiam, Washington, began in 1952 and ended in 1969. The experiment tested high and low thinnings, both at 3- and 6-year intervals. Volumes removed in thinning ranged from 7 to 107 percent of the gross merchantable cubic volume increment accrued during the experiment.

Compared to the control areas, thinning increased the average diameter growth rate of remaining trees. Merchantable gross growth apparently was not reduced by thinning. The efficiency of the residual growing stock was increased, as growth percent was higher in thinned stands. Thinning had no appreciable effect on mortality. The repeated thinnings, however, did salvage much of the merchantable mortality that would otherwise have been lost.

## INTRODUCTION

This study on the Hemlock Experimental Forest[1/] was an investigation of growth and yield of 50-year-old western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) commercially thinned several times. The Forest is located in Grays Harbor County, Washington, 10 miles north of Hoquiam (fig. 1). The stand when first thinned in 1952 was nearly pure western hemlock with less than 10 percent (by cubic volume) Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). The treatments were a series of high and low thinnings at 3- and 6-year intervals in well-stocked, even-aged hemlock. A cost analysis, which is essential for the final evaluation of efficiency of different thinning regimes, is not contained in this paper.

[1/] The Hemlock Experimental Forest was established in 1949 as a cooperative research effort of the St. Regis Paper Company and the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

There are few published reports dealing with commercial thinnings in older stands of western hemlock. A 5-year growth study by Warrack (1960) in a 60-year-old stand in British Columbia revealed that basal area growth was nearly the same for thinned stands as it was for unthinned stands.

A progress report prepared by Staebler (1957) investigated initial responses to thinning on the Hemlock Experimental Forest. This interim report compared high and low thinnings at 3-year intervals, after two repeated thinnings, with an unthinned area. The ratio of gross growth to growing stock (growth percent) was larger in the thinned areas, with high thinning having the largest growth percent. Realized increment (volume harvested in thinning plus the volume added to growing stock) showed a pronounced advantage for thinning. This was due primarily to mortality being salvaged in the thinned areas.

Williamson (1966) recorded the d.b.h. growth of 60-year-old trees in a nearby shelterwood study on the Hemlock Experimental Forest. He found

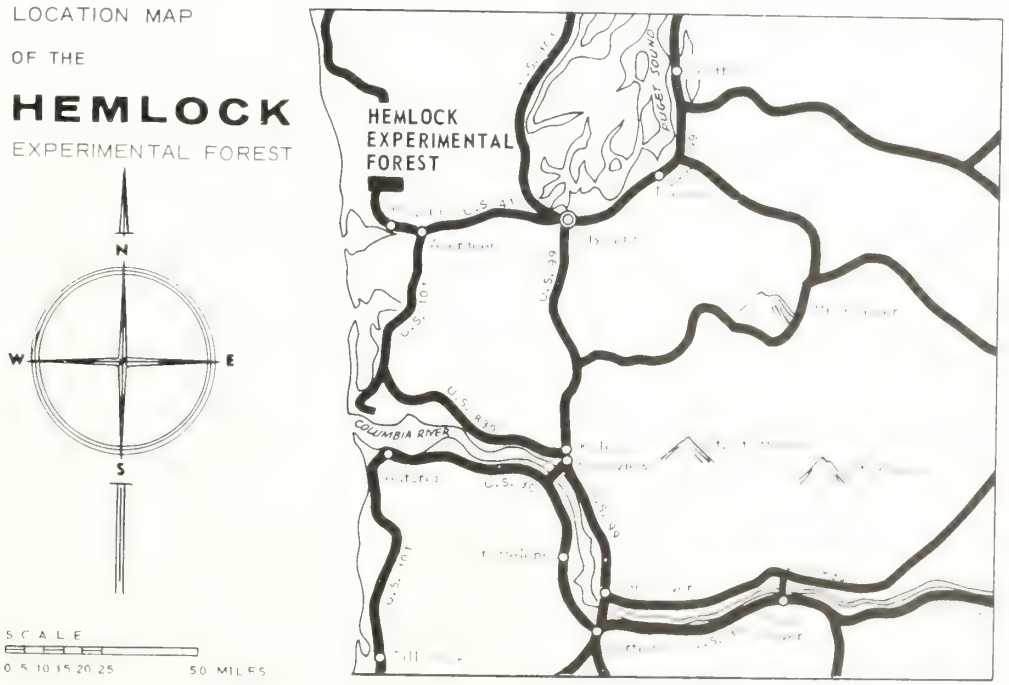


*Figure 1.--Location of the Hemlock Experimental Forest.*

that the diameter increment of dominant and codominant trees in areas with less than 80 trees per acre (198 per ha) was almost twice that of comparable trees in lightly cut stands.

A 17-year thinning study in southwest Alaska revealed that a 96-year-old stand of western hemlock and Sitka spruce responded well to thinning (Farr and Harris 1971). Thinning increased diameter increment on the residual trees and also removed many trees that would have died during the 17-year period.

## METHODS

### DESIGN OF STUDY

Treatments were laid out in compartments[2/] A, B, and C as follows (fig. 2):

| Treatment | Thinning method and interval |
|---|---|
| A-1 | Low, 3 years |
| A-2 | Unthinned control |
| A-3 | Low, 6 years |
| B-1 | High, 3 years |
| B-2 | Unthinned control |
| B-3 | High, 6 years |
| C-1 | High, 3 years |
| C-2 | Unthinned control |
| C-3 | Low, 6 years |
| C-4 | High, 6 years |
| C-5 | Low, 3 years |

Treatments in compartments A and B were 15 to 25 acres (6 to 10 ha) in size, and treatments in compartment C were 5 to 6 acres (2 to 2.4 ha).

Thinning specifications called for the removal of 85 percent of the gross merchantable cubic-foot[3/] increment for

[2/] Compartment is a convenient term for referring to these larger treatment units.

[3/] Cubic-foot volume to 4-inch (10-cm) top excluding stump. Trees larger than 5.5-inch (14-cm) d.b.h.

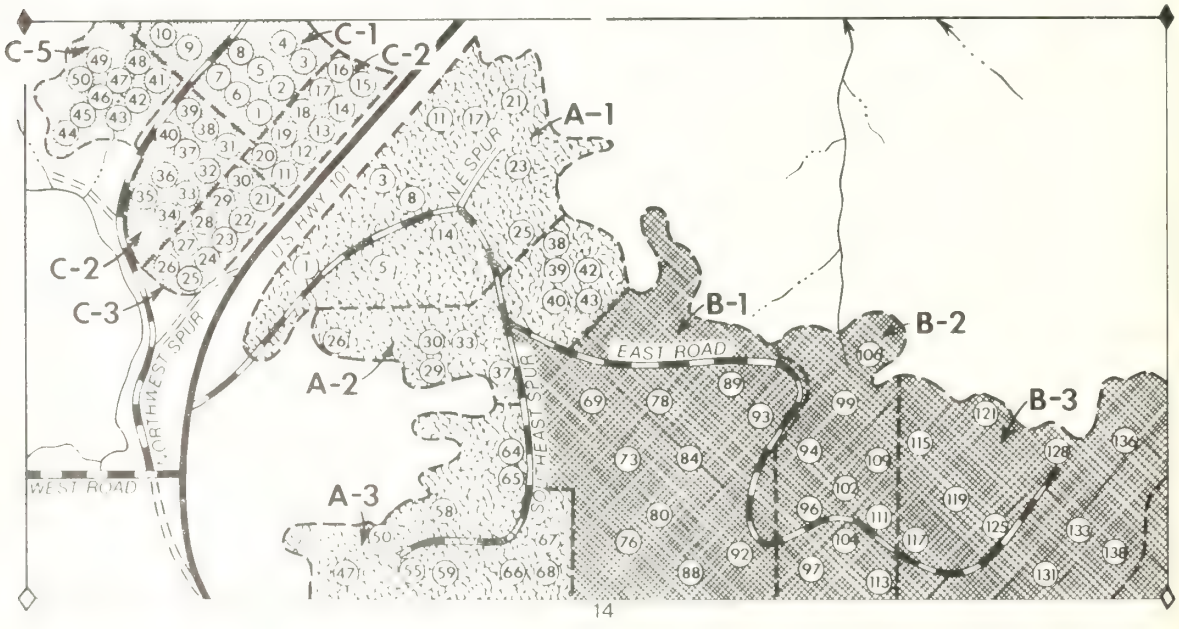


*Figure 2.--Field layout of thinning treatments (N 1/2 sec. 14, T. 19 N., R. 10 W., W. M.).*

the 3- or 6-year period at each thinning. The goal was to remove trees that averaged 3 inches below average stand d.b.h.[4/] for low thinnings, and 3 inches above average stand d.b.h. for high thinnings.

Some thinnings were not made precisely at the 3- or 6-year intervals. Also, treatment periods were different for the three compartments (figs. 3a and 3b).

The original experimental design was not followed, and the originally-planned statistical comparisons could not be made. Each treatment should be compared *only* to the unthinned control in the corresponding compartment. Even though there are essentially three distinct experimental compartments, any gross differences due to thinning should be apparent.

[4/] Average diameter is the diameter of the tree of average basal area for trees larger than 5.5-inch (14-cm) d.b.h.

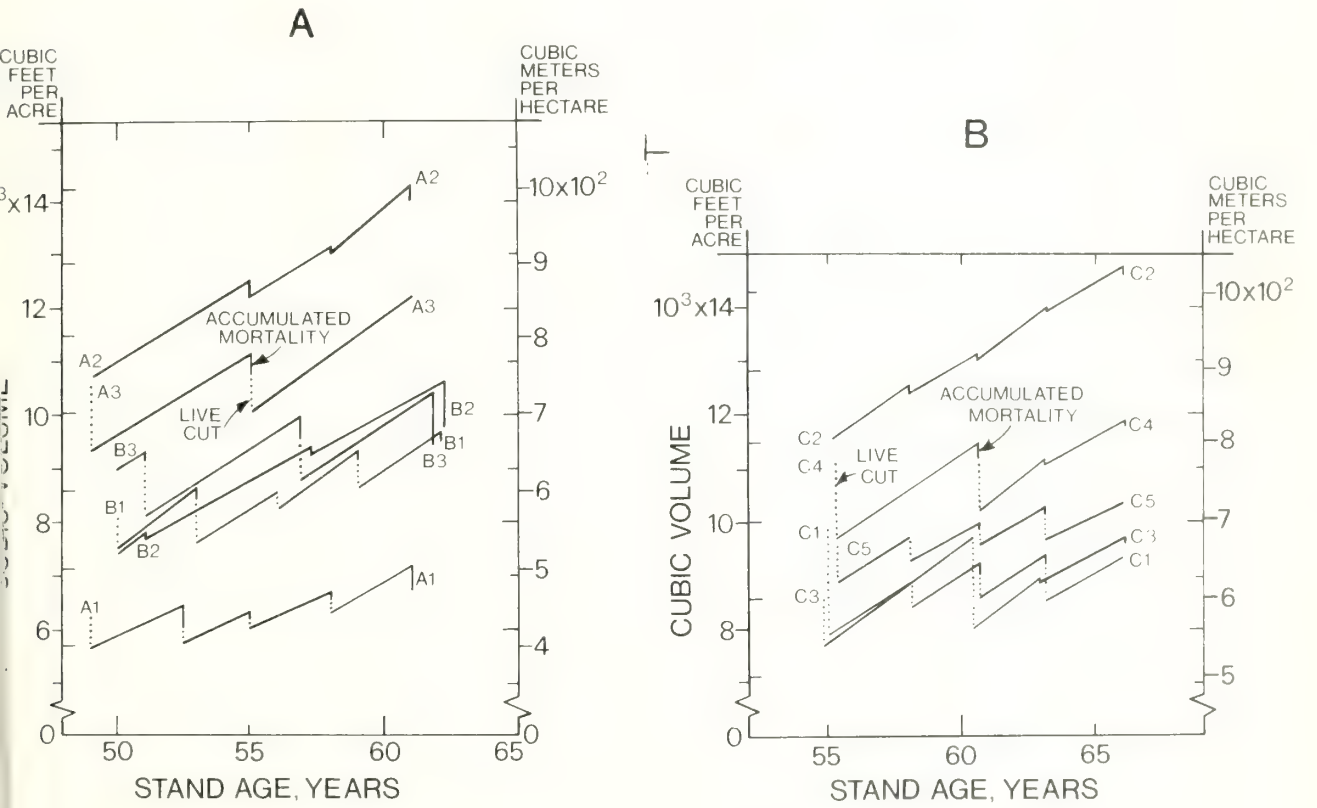


*Figure 3a and 3b.--Severity of thinnings (cubic volume to 4-inch (10-cm) top, trees larger than 5.5-inch (14-cm) d.b.h.)*

MEASUREMENTS

Measurements were recorded on 10 permanent sample plots in each treatment prior to thinnings. Concentric 1/40-acre (101-$m^2$) and 1/10-acre (905-$m^2$) circular plots were systematically located. All trees larger than 5.5-inch (14-cm) d.b.h. were tallied on the 1/10-acre plot, and trees larger than 1.5-inch (4-cm) d.b.h. were tallied on the 1/40-acre plot. Measured trees were tagged, and their diameters were recorded to the nearest 0.1 inch (2.5 mm) at each measurement. Heights were measured on selected trees in 1952, 1959, and 1968. Additional silvicultural data such as crown class and tree damage were also recorded for each tree.

DETERMINATION OF VOLUME AND VOLUME GROWTH

Cubic volume to a 4-inch (10-cm) top excluding stump for trees larger than 5.5-inch (14-cm) d.b.h. was used to analyze growth and yield because the experiment consisted of *commercial* thinnings, with control of thinnings based only on trees larger than 5.5-inch (14-cm) d.b.h. Sound tree volumes were used since little defect was present.

Volumes were assigned to individual trees according to the Comprehensive Tree-Volume Tarif Tables (Turnbull et al. 1972). Actual calculations were performed with the computerized tarif equations (Brackett 1973). Tarif numbers were determined in each compartment for the base periods of 1952, 1959, and 1968 when sample heights were taken. Appropriate tarif numbers for each measurement were determined by linear interpolation between these base periods. Plot volumes were multiplied by the necessary expansion factors to arrive at total volumes per acre.

The two measures of growth used in this paper, gross growth and realized growth, are defined by the following equations (Husch et al. 1972):

$$\Delta V_{gross} = V_{end} - V_{initial} + V_{cut} + V_{mortality}$$

$$\Delta V_{realized} = V_{end} - V_{initial} + V_{cut} + V_{mortality\ cut}$$

Both measures of growth include ingrowth and also growth on trees that later died or were cut. Ingrowth accounted for a negligible part of the gross or realized growth during the experiment.

## STUDY AREA

The Hemlock Experimental Forest lies on gentle to medium slopes at elevations of 225 to 410 feet (70 to 127 m). Both climate and soil are favorable for rapid tree growth. Average annual rainfall is 100 inches (254 cm) with 20 to 25 inches (51 to 64 cm) falling during the growing season (Dimock and Herman 1963). Snow accounts for only a small percentage of the total precipitation. Long term average annual temperature is 50°F (10°C), with an average growing-season temperature of 56°F (13°C). There are occasional periods of freezing temperatures during the winter months. Hoquiam clay loam, a moderately deep, well-drained forest soil, covers almost the entire experimental area.

PRE-TREATMENT STAND

The pure, even-aged western hemlock stand originated in 1903 after old-growth logging. A few scattered trees remained from the original old-growth stand, many of which were poor quality and infected with mistletoe (Staebler 1957). Some were cut in thinning and their removal favored remaining trees.

Initial stand characteristics varied considerably for the various treatments (table 1). Treatment A-1 contained fewer trees and less cubic volume (57 percent) than its control, A-2. Treatment B-2 had considerably fewer trees than other treatments in compartment B. Treatment C-3 had more smaller trees than its control C-2, resulting in a lower averaged d.b.h. in treatment C-3.

Large trees remaining from the original old-growth stand accounted for part of the variation in average d.b.h. between treatments.

Site index for all treatments averaged 157 feet (49 m) at 100 years, a low site class II, based on Barnes' (1962) revised site index curves.

Variations in site index and stand structure account for part of the differences between initial stand characteristics and also tended to mask the real effects of thinning. Gross differences caused by thinning were apparent over the length of the treatment periods (11-12 years).

Table 1--*Descriptive characteristics of treatments before thinning*

| Treatment, thinning method, and interval | Year | Age | Trees per acre | Average d.b.h.[1/] | Merchantable volume per acre[2/] |
|---|---|---|---|---|---|
| | | Years | Number[3/] | Inches[4/] | Cubic feet[5/] |
| A-1 Low, 3 years | 1952 | 49 | 195 | 12.06 | 6,182.1 |
| A-2 Control | 1952 | 49 | 275 | 13.26 | 10,760.5 |
| A-3 Low, 6 years | 1952 | 49 | 252 | 13.74 | 10,670.4 |
| B-1 High, 3 years | 1953 | 50 | 259 | 12.59 | 8,155.1 |
| B-2 Control | 1953 | 50 | 169 | 14.78 | 7,433.0 |
| B-3 High, 6 years | 1953 | 50 | 260 | 13.20 | 8,966.0 |
| C-1 High, 3 years | 1958 | 55 | 282 | 12.65 | 9,837.7 |
| C-2 Control | 1958 | 55 | 250 | 14.38 | 11,540.9 |
| C-3 Low, 6 years | 1958 | 55 | 330 | 11.18 | 8,697.9 |
| C-4 High, 6 years | 1958 | 55 | 265 | 13.88 | 11,331.4 |
| C-5 Low, 3 years | 1958 | 55 | 237 | 13.55 | 9,611.4 |

[1/] Trees larger than 5.5-inch (14-cm) d.b.h.

[2/] Cubic-foot volume to 4-inch (10-cm) top excluding stump. Trees larger than 5.5-inch (14-cm) d.b.h.

[3/] Trees per hectare = trees per acre X 2.47.

[4/] Centimeters d.b.h. = inches d.b.h. X 2.54.

[5/] Cubic meters per hectare = cubic feet per acre ÷ 14.29.

RITY OF THINNINGS

tanding cubic volumes at the end of experiment were greater than initial nes for all treatments except C-1 s. 3a and 3b). Cubic volume of ing stocks was increased by 12, 11, 4 percent for thinned treatments in artments A, B, and C, compared to 30, and 27 percent for their respec- controls.

hinnings were light by present day dards (fig. 4). An average of 79 ent of the gross cubic-foot incre- was thinned in compartment C, e averages of 53 and 54 percent were ed in compartments A and B, respec- y. Thinnings removed 107 percent e gross increment in treatment C-1. figures also indicate that thin- in compartments A and B were much er than the original proposal to e 85 percent of the gross cubic- increment. Because considerable was taken to approximate the ercent" thinning goal, results fur- indicate the difficulty in accu- y attaining such thinning control.

*Figure 4.--A 60-year-old western hemlock stand (treatment C-5) after second low thinning at 3-year intervals.*

## STAND DEVELOPMENT

### MORTALITY

Mortality accounted for 18, 27, and 9 percent of the gross merchantable growth for compartments A, B, and C

Table 2--[illegible] 1/ [illegible]

| Treatment, thinning method, and interval | Treatment period | Initial volume | Ending volume | Live cut | Total mortality 2/ | Mortality cut | Gross increment | Gross p.a.i. 3/ | Growth percent 4/ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Cubic feet per acre 5/ | | | | | |
| A-1 Low, 3 years | 1952-1964 | 6,182.1 | 6,696.2 | 1,597.9 | 848.2 | 254.7 | 2,960.2 | 246.7 | 3.96 |
| A-2 Control | 1952-1964 | 10,760.5 | 14,089.5 | 0.0 | 682.5 | 0.0 | 4,011.5 | 334.3 | 2.72 |
| A-3 Low, 6 years | 1952-1964 | 10,670.4 | 12,255.2 | 2,045.1 | 312.1 | 243.3 | 3,942.0 | 328.5 | 3.09 |
| B-1 High, 3 years | 1953-1965 | 8,155.1 | 9,551.1 | 2,325.2 | 465.9 | 235.2 | 4,187.1 | 348.9 | 4.12 |
| B-2 Control | 1953-1965 | 7,433.0 | 9,674.3 | 0.0 | 1,161.9 | 0.0 | 3,403.2 | 283.6 | 3.22 |
| B-3 High, 6 years | 1953-1965 | 8,966.0 | 9,475.8 | 2,014.8 | 1,318.0 | 224.8 | 3,842.6 | 320.2 | 3.58 |
| C-1 High, 3 years | 1958-1969 | 9,837.7 | 9,316.4 | 3,611.4 | 279.1 | 66.7 | 3,369.2 | 306.3 | 3.49 |
| C-2 Control | 1958-1969 | 11,540.9 | 14,638.2 | 0.0 | 364.8 | 0.0 | 3,462.1 | 314.7 | 2.39 |
| C-3 Low, 6 years | 1958-1969 | 8,697.9 | 9,657.8 | 2,459.8 | 276.1 | 0.0 | 3,695.8 | 336.0 | 3.81 |
| C-4 High, 6 years | 1958-1969 | 11,331.4 | 11,843.3 | 2,631.2 | 434.2 | 0.0 | 3,577.3 | 325.2 | 3.02 |
| C-5 Low, 3 years | 1958-1969 | 9,611.4 | 10,377.3 | 1,915.9 | 187.9 | 48.1 | 2,869.7 | 260.9 | 2.69 |

1/ Cubic-foot volume to a 4-inch (10-cm) top excluding stump. Trees larger than 5.5-inch (14-cm) d.b.h.

2/ Includes mortality cut.

3/ Gross periodic annual increment = gross increment : number of years in treatment period.

4/ Percent of average volume present during experiment.

5/ Cubic-meter volume per hectare to a 10-cm top = cubic-foot volume per acre to a 4-inch top ÷ 14.29.

table 2, column 6). Most of the merchantable volume lost to mortality resulted from two climatic disturbances. A heavy, wet snow that fell during the latter half of January 1954 caused some breakage of tall, slender trees in compartments A and B (Staebler 1957a). The 1962 Columbus Day windstorm caused considerable blowdown of larger trees. Thinning apparently did not have much effect on the volume lost to mortality since storm damage was erratic and unrelated to the type of thinning.

Suppression caused the death of some smaller trees. Although control areas C-2 and C-2 lost more trees to suppression than other treatments in their compartments, there was not enough evidence to conclude that thinning had any appreciable effect on forestalling mortality due to suppression.

NUMBER OF TREES

The number of live trees thinned was consistent with the initial stocking levels and types of thinning applied (table 3). Fewer, but larger, trees were removed in high thinnings than in low thinnings. Erratic storm damage accounted for much of the variation in the number of trees lost to mortality.

AVERAGE DIAMETER

Low thinnings removed trees that were less than the average d.b.h. on all compartments, and high thinnings removed trees larger than the average stand d.b.h. (table 4). In general, thinnings removed larger trees than did mortality. The slight increase in average d.b.h. for mortality in some treatments was due to the death of larger trees during the two climatic disturbances.

The results of thinnings cannot be evaluated properly unless consideration is given to the sizes of the trees produced rather than merely to the volume they represent (Smith 1962). The most common method of testing different treatments is to compare their average diameters. This method is adequate if the comparisons are made between equal numbers of crop trees per acre. For this reason, the average diameter growth for the largest surviving 40 trees per acre (4 per 1/10-acre plot) was used (table 4). Selecting the largest 40 trees per acre is commensurate with the European density standard of 100 trees per hectare. These trees were all dominants or codominants--complete release of some of these trees

Table 3--*Number of trees greater than 5.5-inch (14-cm) d.b.h. per acre before and after thinnings, removed in thinnings, and mortality*

| Treatment, thinning method, and intervals | Treatment period | Before thinning | Live cut | Mortality | After thinning |
|---|---|---|---|---|---|
| | | Number[1/] per acre | | | |
| A-1 Low, 3 years | 1952-1964 | 195 | 71 | 35 | 97 |
| A-2 Control | 1952-1964 | 275 | -- | 42 | 233 |
| A-3 Low, 6 years | 1952-1964 | 252 | 77 | 26 | 149 |
| B-1 High, 3 years | 1953-1965 | 259 | 49 | 35 | 191 |
| B-2 Control | 1953-1965 | 169 | -- | 29 | 144 |
| B-3 High, 6 years | 1953-1965 | 260 | 39 | 51 | 178 |
| C-1 High, 3 years | 1958-1969 | 282 | 56 | 22 | 208 |
| C-2 Control | 1958-1969 | 250 | -- | 31 | 223 |
| C-3 Low, 6 years | 1958-1969 | 330 | 86 | 21 | 246 |
| C-4 High, 6 years | 1958-1969 | 265 | 44 | 27 | 194 |
| C-5 Low, 3 years | 1958-1969 | 237 | 78 | 15 | 152 |

[1/] Number trees per hectare = number trees per acre X 2.47.

Table 4--*Average breast high diameters of all trees greater than 5.5-inch (14-cm) d.b.h. and 40 largest trees per acre, before and after thinning, removed in thinning, and mortality*

| Treatment, thinning method, and interval | Treatment period | Trees > 5.5-inch d.b.h. Average d.b.h. | | | | Forty largest trees per acre Average d.b.h.[1/] | | |
|---|---|---|---|---|---|---|---|---|
| | | Before thinning | Cut | Mortality | After thinning | Before thinning | After thinning | p.a.i.[2/] |
| | | Inches[3/] | | | | Inches[3/] | | |
| A-1 Low, 3 years | 1952-1964 | 12.06 | 10.25 | 10.36 | 16.34 | 17.16 | 20.33 | 0.26 |
| A-2 Control | 1952-1964 | 13.26 | -- | 8.96 | 15.36 | 20.09 | 22.23 | .18 |
| A-3 Low, 6 years | 1952-1964 | 13.74 | 11.07 | 8.07 | 17.75 | 20.82 | 23.22 | .20 |
| B-1 High, 3 years | 1953-1965 | 12.59 | 14.74 | 8.50 | 14.30 | 17.95 | 20.81 | .24 |
| B-2 Control | 1953-1965 | 14.78 | -- | 13.27 | 16.39 | 21.46 | 23.20 | .16 |
| B-3 High, 6 years | 1953-1965 | 13.20 | 15.42 | 10.89 | 14.72 | 19.03 | 21.36 | .21 |
| C-1 High, 3 years | 1958-1969 | 12.65 | 16.60 | 8.14 | 13.58 | 18.22 | 20.70 | .23 |
| C-2 Control | 1958-1969 | 14.38 | -- | 7.91 | 16.21 | 22.46 | 24.44 | .18 |
| C-3 Low, 6 years | 1958-1969 | 11.18 | 11.43 | 8.28 | 12.80 | 17.09 | 19.26 | .20 |
| C-4 High, 6 years | 1958-1969 | 13.88 | 16.09 | 9.01 | 15.52 | 19.85 | 22.26 | .22 |
| C-5 Low, 3 years | 1958-1969 | 13.55 | 10.68 | 8.16 | 16.53 | 22.35 | 24.38 | .18 |

[1/] D.b.h. of 4 largest surviving trees per plot (a density of 40 per acre = 100 per hectare).

[2/] Periodic annual increment in inches d.b.h.

[3/] Centimeters d.b.h. = inches d.b.h. X 2.54.

robably did not occur until late in he experiment. Periodic annual increent for average diameter was larger or all thinned treatments compared to heir respective controls (table 4). his is an excellent indication that hinning redistributed the growth to he larger trees.

## ROWTH AND YIELD

### otals for Experiment

Summaries of the growth and yield of he various treatments for the entire xperiment are presented in table 2. he treatment period was different mong compartments A, B, and C, hence reatments should be compared only to he unthinned control in the corresponding compartment.

Thinning apparently did not reduce ross growth relative to the unthinned tands. When gross increment is expressed as a percent of initial volume, he growth on the thinned treatments as nearly the same or greater than heir respective controls. Cubic olume growth for the experiment averged 42, 47, and 35 percent of the nitial volumes for the thinned treatents in compartments A, B, and C, compared to 37, 46, and 30 percent for heir respective controls.

Statistical tests (unpaired t-tests) etween thinned treatments and the ontrol on compartment C showed no ignificant differences in growth. ross growth on each of the 10 plots or each treatment, expressed as a ercent of initial volume, were used s the test observations. No additional statistical tests were made ecause of inadequate experimental esign.

Growth percent, the ratio of gross rowth to growing stock, provides a easure of efficiency of residual growg stock. It is one of the most effecive measures for comparing treatment ffects when initial volumes are difrent. Growth percent was higher on l thinned treatments relative to eir controls (table 2, column 10). his is another good indication that owth was adequately transferred to e residual stands after thinning. me of the increase in growth percent, wever, is due to the less efficient ees being removed (Reukema 1972).

There were no consistent advantages revealed for low thinning versus high thinning nor for light thinning versus heavy thinning.

### Trends in Periodic Growth

The trends in periodic growth did not appear to be related to either the type of thinning or level of growing stock. Changes in growth rates for thinned treatments were similar to their respective control areas (figs. 3a and 3b). In response to above-average rainfall in 1963 and 1964, periodic increment increased for most treatments over the measurement period that spanned these 2 years.

### Realized Volume

One of the major objectives of thinning is to utilize all of the merchantable material produced by the stand during the rotation (Smith 1962). Realized increment, which is the volume harvested in thinning plus the volume added to growing stock, showed an advantage for thinning (table 5). This is because repeated thinnings at frequent intervals salvage merchantable mortality that would have otherwise been lost.

Not much of the mortality was salvaged on treatments A-1 and B-3 because the thinning experiment ended for these treatments just after the Columbus Day windstorm of 1962. Most of the large trees lost to mortality during this storm would have been salvaged if thinnings had been continued.

The size of the mortality trees that were salvaged was not related to the type of thinning. High thinning salvaged smaller trees, just as low thinning did. Also, low thinning salvaged the larger trees lost to climatic disturbances.

Total realized volumes produced by each treatment for the entire experiment are also listed in table 5. As noted previously, treatment periods were of different lengths for compartments A, B, and C. Total realized volume is the ending volume plus live cut and mortality cut. This figure represents the total merchantable production for each treatment if it were logged at the ending date. Total realized volume, expressed as a percent of initial volume, indicates an advantage for thinning in all compartments.

Table 5--*Merchantable*[1/] *cubic volume realized increment and total realized volume*

| Treatment, thinning method, and interval | Treatment period | Gross increment | Realized increment | Realized, percent of gross | Realized volume | |
|---|---|---|---|---|---|---|
| | | Cubic feet per acre[2/] | | Percent | Cubic feet per acre[2/] | Percent[3/] |
| A-1 Low, 3 years | 1952-1964 | 2,960.2 | 2,366.7 | 80 | 8,548.8 | 138 |
| A-2 Control | 1952-1964 | 4,011.5 | 3,329.0 | 83 | 14,089.5 | 131 |
| A-3 Low, 6 years | 1952-1964 | 3,942.0 | 3,873.2 | 98 | 14,543.6 | 136 |
| B-1 High, 3 years | 1953-1965 | 4,187.1 | 3,956.4 | 94 | 12,111.5 | 149 |
| B-2 Control | 1953-1965 | 3,403.2 | 2,241.3 | 66 | 9,674.3 | 130 |
| B-3 High, 6 years | 1953-1965 | 3,842.6 | 2,749.4 | 72 | 11,715.4 | 131 |
| C-1 High, 3 years | 1958-1969 | 3,369.2 | 3,156.8 | 94 | 12,994.5 | 132 |
| C-2 Control | 1958-1969 | 3,462.1 | 3,097.3 | 89 | 14,638.2 | 127 |
| C-3 Low, 6 years | 1958-1969 | 3,695.8 | 3,419.7 | 93 | 12,117.6 | 139 |
| C-4 High, 6 years | 1958-1969 | 3,577.3 | 3,143.1 | 88 | 14,474.5 | 128 |
| C-5 Low, 3 years | 1958-1969 | 2,869.7 | 2,729.9 | 95 | 12,341.3 | 128 |

[1/] Cubic-foot volume to a 4-inch (10-cm) top excluding stump. Trees larger than 5.5-inch (14-cm) d.b.h.

[2/] Cubic-meter volume per hectare to a 10-cm top = cubic-foot volume per acre to a 4-inch top × 14.29.

[3/] Percent of initial volume.

## DISCUSSION AND CONCLUSIONS

The considerable differences in initial stand characteristics for controls versus thinned stands, plus the failure to follow the original experimental design specifications, prevent obvious and sensitive comparisons. Results, however, appear to show that thinning on the Hemlock Experimental Forest satisfied the two fundamental objectives of thinning (Smith 1962): (1) the growth of the stand was adequately redistributed to the residual stand after thinning, and (2) nearly all of the merchantable material produced by the stand was utilized. Thinning increased the average diameter growth rate compared to the control areas. Merchantable gross growth apparently was not reduced by thinning. When the growth was expressed as a percent of the average volume present (growth percent), thinned treatments showed an avantage over the control areas. The efficiency of the residual growing stock was apparently increased by thinning. Thinning had no appreciable effect on mortality. The repeated thinnings, however, did salvage most of the merchantable mortality that would have otherwise been lost. This fact is reflected in higher realized increments and total productions (expressed as a percent of initial volume) for the thinned treatments compared to their control areas.

Although thinning in general revealed distinct advantages over unthinned control areas, there was no conclusive evidence that any one particular thinning treatment was any better than another.

Forest and land managers should remember that young western hemlock actually out-produces young Douglas-fir in net yield per acre on many sites (Dimock 1958). They must evaluate both silvicultural information and logging economics if they are to develop appropriate commercial thinning specifications. Extension of these study results together with other available commercial thinning information, gives manager of young western hemlock forests another facet of knowledge to help them make thinning decisions.

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During 11- to 12-year treatment periods, beginning at ages 49 to 55, low and high commercial thinnings, at 3- and 6-year intervals, improved diameter growth of residual trees. Gross merchantable growth per acre apparently was not reduced by thinning. Thinning had no appreciable effect on mortality.

KEYWORDS: Thinning (commercial), commercial thinning, growth response, yield (forest), western hemlock, *Tsuga heterophylla*, Washington (Hemlock Experimental Forest), Hemlock Experimental Forest--Washington.

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## Metric Equivalents

1 acre = 0.405 hectare

1 foot = 0.3048 meter

1 inch = 2.54 centimeters

1 square foot per acre = 0.229 568 square meter per hectare

# *FINANCIAL PRECOMMERCIAL THINNING GUIDES FOR NORTHWEST PONDEROSA PINE STANDS*

## Reference Abstract

Sassaman, Robert W., James W. Barrett, and Asa D. Twombly. 1977. Financial precommercial thinning guides for Northwest ponderosa pine stands. USDA For. Serv. Res. Pap. PNW-226, 27 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This paper describes a flexible management tool designed to be applicable to thinning alternatives for an infinite number of combinations of crop tree size and vigor, site quality, thinning costs, stumpage prices, and three discount rates.

KEYWORDS: Precommercial thinning, thinning (precommercial), improvement cutting, forestry business economics, economics (forestry business), site class, diameter increment, increment (diameter), stumpage prices, cost and return accounting (forestry), timber management planning, ponderosa pine, *Pinus ponderosa*, Pacific Northwest.

## RESEARCH SUMMARY

**Research Paper PNW-226**

**1977**

Financial precommercial thinning guides for Pacific Northwest ponderosa pine (*Pinus ponderosa* Laws.) stands are reported for an infinite number of combinations of crop tree size and vigor, site quality, thinning costs, stumpage prices, and three discount rates. These guides are the result of a cooperative effort of the Pacific Northwest Forest and Range Experiment Station and Region 6 of the National Forest System (NFS). The guides represent a flexible forest management tool that is based on financial returns from increased timber production expressed as benefit/cost ratios; they are of most use to NFS managers.

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# INTRODUCTION

Forest managers in the ponderosa pine (*Pinus ponderosa* Laws.) areas of the Pacific Northwest are often faced with the responsibility of establishing precommercial thinning priorities for timber stands of widely varying location, size, and growth characteristics. The thinning priority of an individual stand may be influenced by consideration of a variety of resource uses and concerns. Financial implications (costs and benefits) associated with the estimated harvestable wood production of thinned stands often have a major impact on the selection of thinning priorities.

This paper describes the development and use of financial precommercial thinning guides for stands of ponderosa pine in the Pacific Northwest. These guides are the result of a cooperative effort of the Pacific Northwest Forest and Range Experiment Station and Region 6 of the U.S. Forest Service. They are a flexible management tool designed to be applicable to thinning alternatives for an infinite number of combinations of crop tree size and vigor, site quality, thinning costs, stumpage prices, and three discount rates. The paper was written primarily to help National Forest System (NFS) managers identify their most financially attractive precommercial thinning opportunities.

The guides are based on a stand analysis (rather than a forest analysis) approach and on numerous NFS policies determined on other than a financial basis.[1/] Therefore, the value of these guides to industrial forest managers and other public forest managers will be limited to the extent that their agency's policies agree with the assumptions built into these guides.

Financial precommercial thinning guides are important to forest managers in two ways. First, since opportunities to thin usually exceed what the budget can finance, forest managers can accomplish more with their budget by using the guides to select the most financially attractive precommercial thinning opportunities.

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[1/] Use of a stand analysis excludes consideration of any effects that precommercial thinning may have on the flow of timber harvests on a forest. As such, a stand analysis does not include consideration of the allowable cut effect (Schweitzer et al. 1972) or any other forestwide timber harvest flow constraints. The most direct application of a stand analysis is to set financial priorities among stands for treatment. Costs and benefits not measured in dollars must also be considered when final priorities are set. At higher levels of decisionmaking, additional evaluations of programs of treatments may be needed. A thinning program may have important environmental, esthetic, and wildlife impacts not considered in a stand analysis. At this level, the impact of the program on the allowable cut level and the cash flow from the unit will also likely interest decisionmakers.

Second, these financial precommercial thinning guides are important to forest managers because they provide a consistent regionwide approach to identifying the most financially attractive precommercial thinning alternatives. This consistency will benefit the forest manager when he attempts to set thinning priorities based on the financial ranking and the nontimber and amenity values of the alternatives.

## DESCRIPTION OF THE GUIDES

The thinning guides are represented by benefit/cost ratios (B/C) determined through a marginal financial analysis of the thinning alternatives. B/C is one of several ways economists have developed to judge competing financial investments. The theoretical reason for its use in this analysis is the presence of a budget constraint. If we could assume that all required funds would be available, then a budget constraint would not exist and present net worth would be a more appropriate criterion (Webster 1965). In its simplest form, a B/C for a thinning investment is obtained by dividing the benefits of a thinning project by the thinning costs:

$$\frac{\text{benefits of thinning}}{\text{costs of thinning}} = \text{benefit/cost ratio.}$$

Usually, the analysis is more complex because the timing of the benefits and costs is important. Precommercial thinning costs are incurred immediately, but the benefits are not realized until the time of the commercial thinnings and the final harvest. Because society places a time preference on money (one would normally prefer "x" dollars today than sometime in the future), the future benefits of thinning must be reduced to reflect their present value before dividing them by the cost of thinning, already expressed in present value, to obtain a B/C. Therefore, the B/C is more aptly stated as:

$$\frac{\text{present value of benefits of thinning}}{\text{present value of costs of thinning}} = \text{benefit/cost ratio.}$$

The reduction of future benefits to present value is called discounting. The discount rate is the interest rate used to reduce future benefits and costs to their present value. Agency policy will dictate the proper discount rate.

B/C is a convenient vehicle for comparing investment alternatives because it is a relatively simple numerical index. A B/C greater than 1.0 indicates that measurable benefits exceed measurable costs. The more a B/C exceeds 1.0, the more financially attractive is the investment (and the better the thinning opportunity). When the B/C equals 1.0, benefits and cost are equal. When a B/C is less than 1.0, measurable costs exceed measurable benefits. And, if a B/C is equal to zero, there are no net measurable benefits to consider, only costs.

A note of caution is in order. One might conclude that a thinning alternative with a B/C of less than 1.0 should automatically be eliminated from further consideration and that thinning priorities should be based on higher B/C's ahead of lower ones. Such a conclusion would be premature, however, because although a financial evaluation of measurable costs and benefits is important in selecting precommercial thinning opportunities, amenity values that are not readily translated into dollars often need to be considered. These values include esthetics, dispersed recreation opportunities, wildlife habitat, and fire danger reduction. These values may be costs or benefits. Therefore, the most important point to remember in the use of these guides as a ranking tool is that they provide only a financial ranking and that final priorities must consider other costs and benefits omitted from the B/C.

Use of B/C is appropriate for our analysis of precommercial thinning alternatives, since our main concern is to *rank* thinning alternatives and thereby identify the most financially attractive ones for funding rather than to determine a specific rate of return for each thinning alternative.

In a B/C analysis of precommercial thinning alternatives, the benefits are expressed as a stumpage price in dollars per thousand board feet ($/MBF) times the additional volume of timber that will be available for harvest in commercial thinnings and the final harvest as a result of the precommercial thinnings. Present value of the benefits is obtained by discounting the benefits to year zero. Costs, expressed in dollars per acre, occur in year zero so they are already expressed in present value and need not be discounted.

Table 1 illustrates a typical B/C calculation for a precommercial thinning alternative; in this case, a stand with high vigor 2-inch crop trees on a high site. Stumpage price is $40 ($30 for commercial thinnings), precommercial thinning costs are $25 per acre, and the discount rate is 5 percent. Column 7 shows the discounted revenue (the present value) of each commercial thinning and the final harvest for situations both with and without a precommercial thinning. The present value of the benefits of the precommercial thinning is the difference of the present values listed in column 7 both with and without precommercial thinning ($28.39-$1.61). The B/C ($1.07) is the difference ($26.78) divided by the cost ($25.00).

A similar calculation could be made for an infinite number of combinations of crop tree diameters, vigor, sites, thinning costs, and stumpage prices. The results of such calculations could be summarized in voluminous tables such as the examples in appendix C for selected costs and prices at a 5-percent discount rate.

Table 1--*An example of the method used to calculate benefit/cost ratios (B/C) for the economic precommercial thinning guides with sample data representing a stand with high vigor 2-inch crop trees on a high site; a 5-percent discount rate is assumed*

| 1 | 2 | 3 | 4 | 5 | 6 | | 7 | | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Age | Time since precommercial thinning | Volume harvested | | Type of harvest[1/] | Harvest revenue[2/] | | Present value of revenue (discounted at 5 percent to year 0) | | Precommercial thinning cost | Present value of precommercial thinning cost[3/] |
| | | With precommercial thinning | Without precommercial thinning | | With precommercial thinning | Without precommercial thinning | With precommercial thinning | Without precommercial thinning | | |
| - - - Years - - - | | Board feet per acre | | | - - - - - - - - - - - Dollars per acre - - - - - - - - - - - | | | | | |
| 13 | 0 | -- | -- | -- | -- | -- | -- | -- | 25.00 | 25.00 |
| 37 | 24 | 1,324 | -- | CT | 39.72 | -- | 12.32 | -- | -- | -- |
| 60 | 47 | 2,891 | -- | CT | 86.73 | -- | 8.76 | -- | -- | -- |
| 80 | 67 | 3,440 | -- | CT | 103.20 | -- | 3.93 | -- | -- | -- |
| 100 | 87 | -- | 2,210 | CT | -- | 66.30 | -- | 0.95 | -- | -- |
| 120 | 107 | -- | 2,688 | CT | -- | 80.64 | -- | .44 | -- | -- |
| 127 | 114 | 21,980 | -- | FH | 879.20 | -- | 3.38 | -- | -- | -- |
| 140 | 127 | -- | 2,792 | CT | -- | 83.76 | -- | .17 | -- | -- |
| 214 | 201 | -- | 21,383 | FH | -- | 855.32 | -- | .05 | -- | -- |
| Total | | | | | | | 28.39 | 1.61 | | |

Present value of the benefits of thinning = $28.39 - $1.61 = $26.78.

$B/C = \frac{\$26.78}{\$25.00} = \$1.07.$

1/ CT is commercial thinning; FH is final harvest.

2/ Based on stumpage prices of $40 per thousand board feet for final harvests and $30 for commercial thinnings.

3/ Present value of precommercial thinning cost is the same as the precommercial thinning cost because it is incurred at year 0 and, therefore, is already expressed as present value.

The problem with this approach is that the user must interpolate B/C values when the precommercial thinning cost-stumpage price combination associated with a thinning alternative is not listed in the B/C tables. If both the cost and the price are not represented in the tables, a double interpolation is required to obtain the relevant B/C. Since a double interpolation is a time-consuming and error-prone procedure, we devised a simpler approach that replaces each B/C table with a B/C factor (F). Consequently, the 16 tables of appendix C could be replaced by 16 B/C factors. These factors, listed in table 2, permit users to calculate B/C's for their thinning alternatives with a simple formula: B/C = F X final harvest price/cost, or B/C = F X P/C. The "Use of the Guides" section shows how to calculate the B/C's by this formula with the worksheet described in figure 1 to construct the thinning guides. A section outlining the derivation of the B/C factors follows, but first observe that the formula containing the B/C factor will produce the same answer (1.07) with the sample data as the typical longer B/C calculation used in table 1. The F value was obtained from table 2 for a high site, high vigor, 2-inch-diameter crop tree at a 5-percent discount rate.

In the next section we outline the logic behind the development of the B/C factors.

Table 2--*Benefit/cost factors for combinations of site quality and vigor and diameters of crop trees at 5-, 7-, and 10-percent discount rates (use with figure 1)*

| Site | Vigor | Diameter at breast height (inches) | | | |
|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 |
| | | 5 Percent | | | |
| High | High | 0.67 | 0.80 | 0.97 | 1.00 |
| High | Medium | .52 | .63 | .76 | .78 |
| Low | High | .49 | .62 | .78 | .86 |
| Low | Medium | .38 | .48 | .61 | .68 |
| | | 7 Percent | | | |
| High | High | .32 | .43 | .59 | .67 |
| High | Medium | .23 | .31 | .42 | .48 |
| Low | High | .22 | .32 | .45 | .56 |
| Low | Medium | .16 | .23 | .32 | .40 |
| | | 10 Percent | | | |
| High | High | .13 | .20 | .31 | .39 |
| High | Medium | .08 | .12 | .19 | .25 |
| Low | High | .08 | .14 | .22 | .31 |
| Low | Medium | .05 | .09 | .14 | .19 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Area | Site (high or low) | Average d.b.h. of leave trees (2, 4, 6, 8 inches) | Crop tree vigor (high or medium) | Precommercial thinning cost (includes slash treatment in dollars per acre | Stumpage value (current price for final harvests, in dollars per thousand board feet) | B/C factor (from table 2) | Benefit/cost ratio at user selected discount rate of __percent[1/] | Financial priority |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |

[1/] Column 7 times column 6 divided by column 5.

*Figure 1.--Worksheet for establishing financial precommercial thinning priorities.*

## METHOD FOR DERIVING B/C FACTORS[2/]

We have stated that in a B/C analysis of precommercial thinning alternatives the financial benefits of the thinnings relate to the additional volume of timber that will be available for harvest in commercial thinnings and the final harvest. We have assumed that the stumpage price for commercial thinnings will equal 75 percent of the stumpage price for final harvests. Present values of benefits are obtained by discounting expected benefits to year zero at a stated discount rate. Precommercial thinning costs are initial costs. As such, they occur in year zero and need not be discounted because they are already expressed in present value.

We developed the B/C factor concept to simplify the B/C calculation and the procedure of using the large B/C tables as the precommercial thinning guides. The B/C factors are derived in the following manner:

$$B/C = \sum_{i=1}^{t} \left(\frac{\Delta ViPi}{df_i}\right)/C.$$

$\Delta Vi$ = change in volume harvest in year i (commercial thinning or final harvest).
$Pi$ = stumpage price for harvest in year i (price for thinnings is 0.75 of price for final harvest).
$df_i$ = discount factor in year i.

If all prices are changed by a factor R, then

$$(B/C)_R = \sum_{i=1}^{t} \left(\frac{\Delta ViPiR}{df_i}\right)/C = R \sum_{i=1}^{t} \left(\frac{\Delta ViPi}{df_i}\right)/C = R(B/C).$$

Likewise, if all costs are changed by a factor R',

$$(B/C)_{R'} = \sum_{i=1}^{t} \left(\frac{\Delta ViPi}{df_i}\right)/CR' = \frac{1}{R'} \sum_{i=1}^{t} \left(\frac{\Delta ViPi}{df_i}\right)/C = \frac{1}{R'}(B/C).$$

Therefore,

$$(B/C)' = \frac{R}{R'} \sum_{i=1}^{t} \left(\frac{\Delta ViPi}{df_i}\right)/C = \frac{R}{R'}(B/C).$$

Recognizing this relationship, we developed B/C factors (F) which are equal to

$$\sum_{i=1}^{t} \left(\frac{\Delta ViPi}{df_i}\right)/C;$$

when: $Pi = 1$ for final harvests,
$Pi = 0.75$ for commercial thinnings, and
$C = 1$.

Therefore, $B/C = F \times P/C$ when P is any final harvest price and C is any cost that the users of these thinning guides may suggest for the stumpage price and precommercial thinning cost associated with their thinning alternatives.

---

[2/] Those not interested in the derivation of B/C factors may wish to turn to the section "Use of the Guides."

## USE OF THE GUIDES

The financial thinning guides are expressed as B/C's, one for each thinning alternative. The guides are in the form of a worksheet (fig. 1). The user calculates the B/C's from these data:

1. Site quality.[3/]
2. Average d.b.h. of crop trees.
3. Average crop tree vigor (as defined by one or more of the tree characteristics listed in table 3).
4. Costs:[4/] *Precommercial thinning*--Direct costs that include layout, contracts, and contract administration. *Slash treatment*--costs for meeting fire management standards.
5. Present stumpage price for final harvests exclusive of road development costs.
6. Discount rate (5, 7, or 10 percent).

A five-step procedure for using the guides is outlined here. Table 4 is a worksheet with sample data. Figure 1 is a blank worksheet which may be photocopied for use.

1. *Define precommercial thinning alternatives.* Assemble data required for each thinning alternative. Sources of this information include stand exam printouts, forest inventory, presale surveys, 5-year action plans, and onsite observations. Use current treatment costs and current stumpage prices for final harvests to define the costs and revenue associated with each precommercial thinning activity. This will insure a consistent approach to the evaluation of thinning alternatives. Future stumpage prices may change, however, and that may affect the apparent financial attractiveness but will not change the financial rankings.

Table 3--*Indicators of crop tree vigor in unthinned natural stands of ponderosa pine*

| Tree characteristics | Vigor | |
|---|---|---|
| | Medium | High |
| Crown ratio | 40 to 60 percent | Greater than 60 percent |
| Most recent decade's growth in diameter | 1/2 to 1 inch | Greater than 1 inch |

[3/] A high site is a site on which dominant and codominant trees have attained an average height of 78 feet at a total age of 100 years; a low site, 70 feet at 100 years (Meyer 1961).

[4/] Costs for thinning and protection usually increase significantly as stand diameter and density increase. Use of a constant cost per acre across a range of average stand diameters is usually inappropriate.

Table 4--*Worksheet (with sample data) for establishing financial precommercial thinning priorities*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Area | Site (high or low) | Average d.b.h. of leave trees (2, 4, 6, or 8 inches) | Crop tree vigor (high or medium) | Precommercial thinning cost (includes slash treatment, in dollars per acre) | Stumpage value (current price for final harvests, in dollars per thousand board feet) | B/C factor (from table 2) | Benefit/cost ratio at selected discount rate of 5 percent[1/] | Financial priority[2/] |
| 1 | H | 4 | H | 25 | 80 | 0.80 | 2.56 | 3 |
| 2 | L | 8 | M | 75 | 120 | .68 | 1.09 | 9 |
| 3 | L | 2 | M | 25 | 120 | .38 | 1.82 | 6 |
| 4 | H | 2 | H | 25 | 120 | .67 | 3.22 | 1 |
| 5 | H | 4 | H | 50 | 120 | .80 | 1.92 | 5 |
| 6 | H | 2 | H | 37.50 | 120 | .67 | 2.14 | 4 |
| 7 | L | 6 | H | 75 | 120 | .78 | 1.25 | 8 |
| 8 | H | 2 | H | 25 | 120 | .67 | 3.22 | 1 |
| 9 | L | 4 | M | 25 | 80 | .48 | 1.54 | 7 |
| 10 | L | 8 | H | 75 | 80 | .86 | .92 | 10 |

[1/] Column 7 times column 6 divided by column 5.

[2/] Priority number 2 is omitted because two areas have the same B/C ratio and are ranked number 1.

2. *List data for thinning alternatives in columns 1 through 6.*
3. *Locate the appropriate B/C factor* for each thinning alternative in table 2 and record them in column 7.
4. *Calculate the B/C* by multiplying the stumpage price (column 6) by the B/C factor (column 7) and dividing by the precommercial thinning cost (column 5). Record the result (B/C) in column 8.
5. *Rank alternatives to establish financial priorities.* Record priority rank in column 9. The most financially attractive thinning alternative, the one with the greatest B/C, should receive the highest ranking (priority). The alternative with the second highest B/C should receive the second highest priority, etc.

Although the above example concerns only stands with no overstory, this procedure may also be useful in stands with a mature overstory and a thinnable understory. For example, a high benefit cost ratio for thinning an understory would indicate the need for an assessment of the thrift and growth of the overstory. Thus, the financial benefits of thinning the understory could influence the timing of converting old growth to second growth. Conceivably, the combination of overstory thrift and understory thinning B/C could be used for ranking stands for overstory removal--a concept that deserves further study. The source of funding for thinning may determine whether it is appropriate to rank stands both with and without overstory, but separately. On National Forests, stands with overstory will often qualify for collection of KV[5/] funds, whereas those without overstory will need to be assigned separate priorities for the use of P&M[6/] funds.

## APPLICATION OF THE GUIDES

Generally, a precommercial thinning opportunity exists in healthy overstocked ponderosa pine stands composed of unmerchantable size trees whenever thinning will not conflict with some higher priority use. Stands considered unmerchantable now but that will contain a salable quantity of merchantable excess trees in 10 years are not considered precommercial thinning opportunities. We are concerned with thinning stands between 1 and 8 inches in d.b.h. Even within these narrow diameter limits the forest manager is confronted with a myriad of stand conditions where thinning opportunities exist. Some of these overstocked stands have an overstory of mature trees displaying varying degrees of thrift. NFS policy is to remove overwood before the understory is thinned. Priorities for overwood removal are shown in appendix B. Stands recognized as high priority candidates for removal of their overstories should be considered for understory treatment. As soon as the overstory is removed, stands with a favorable B/C will become available for thinning.

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5/ Knutson-Vandenberg Act funds set aside from harvest receipts.

6/ Appropriated funds for protection and management.

Great diversity in tree size and density can be found in young ponderosa pine reproduction in the Pacific Northwest. Much of this variation is attributed to past seed production, weather, fire, insects, disease, and logging practices. Sapling stands range from less than 1,000 trees per acre to extremes of 20,000 (fig. 2). Small pole stands can be understocked (less than 60 trees per acre) on the desert fringe or overstocked with several thousand trees per acre on higher sites. It is not unusual for adjacent sapling and pole stands to be the same age. Fire or some other agents often reduce density in a portion of a "dog hair" stand, causing faster growth and resulting in pole-size trees. Therefore, size is not a good indicator of age in overstocked stands.

Ponderosa pine responds to thinning at almost any age (Curtis 1952, Dunning 1922). Response in height and diameter growth of old merchantable ponderosa pine trees is obviously different from that of young trees. We are concerned with stands of crop trees that are 1 to 8 inches in d.b.h. and approximately 10 to 80 years old. Although all 10- to 80-year-old trees of the same size and crown dimension may not respond the same, Barrett (1973) reported that 80-year-old suppressed trees have responded at wide spacings to grow 6 inches per decade or three rings per inch. Many forest managers now recognize that these older suppressed trees have the capacity to respond and grow at acceptable rates. Age is of little concern within the precommercial thinning size classes. The real concern is the influence of crown size on growth.

*Figure 2.--Unthinned ponderosa pine stand about 70 years old.*

Crowns of crop trees left after precommercial thinning vary in size and in their response to release. Therefore, the average vigor of crop tree stands differs between thinning alternatives. To illustrate, consider the typical crop tree sapling growing in a stand of 2,000 trees per acre having 65 percent of its height in crown. Compare this with a crop tree in a stand of 15,000 stems with an overstory where only 40 percent of the trees' height is in the crown. The tree with the smaller crown will require more time to respond to release than the tree with the larger crown. Also, crowns often differ in density, width, and color of needles. These combined characteristics influence the vigor of the tree and consequently the speed and quantity of response of thinning (Dunning 1922).

## BASIS FOR THE GUIDES

Key elements in the basis for the financial precommercial thinning guides are the stocking guides, managed yield estimates and related assumptions for thinned stands, and the investment analysis, including its assumptions and their method of application.

### STOCKING GUIDES

The physical stocking guides used in the estimation of managed yields are commonly called stocking level curves. Basic features of stocking level curves are outlined in the Forest Service Silvicultural Examination and Prescription Handbook (Region 6) and figure 3. By definition in the Handbook, "a stocking level curve is a management tool used to compare the stocking of a given timber stand in relationship to a desired (biologic) stocking level under managed conditions. Generally, the curves express a desired number of trees per acre for a given diameter breast height and/or at a given age by site classes." The curves for ponderosa pine (fig. 3) are based on the growth and yield tables obtained from USDA Bulletin 630 (Meyer 1961), research data from the Pacific Northwest Experiment Station, and observations of growth of stands of various densities throughout Region 6.

The current stocking level curves show three levels of stocking: the maximum, the minimum, and the recommended levels. The upper level (fig. 3) shows the maximum number of trees desired per acre for a range of average tree sizes. It represents the upper limit of stand density beyond which vigor and growth rates deteriorate below those specified by management. The middle curve or recommended level is the density that will occupy the site producing a desirable combination of usable wood and forage for domestic and wildlife needs. The lower curve is the level of stocking that will produce the minimum acceptable yield per acre at the time of regeneration cutting.

Stocking level curves reflect full stocking level control. The recommended stocking level curve shows the number of trees of a certain diameter to be left after the silvicultural treatment is finished. The timing of the precommercial thinning is denoted by the first sharp break in the recommended level curve (point A, fig. 3). The second sharp break in the curve indicates the diameter at which the first commercial thinning will be made, in this instance 10-inch d.b.h. Periodic commercial entry occurs during the curved portion; between 50 and 70 trees are reserved for final harvest.

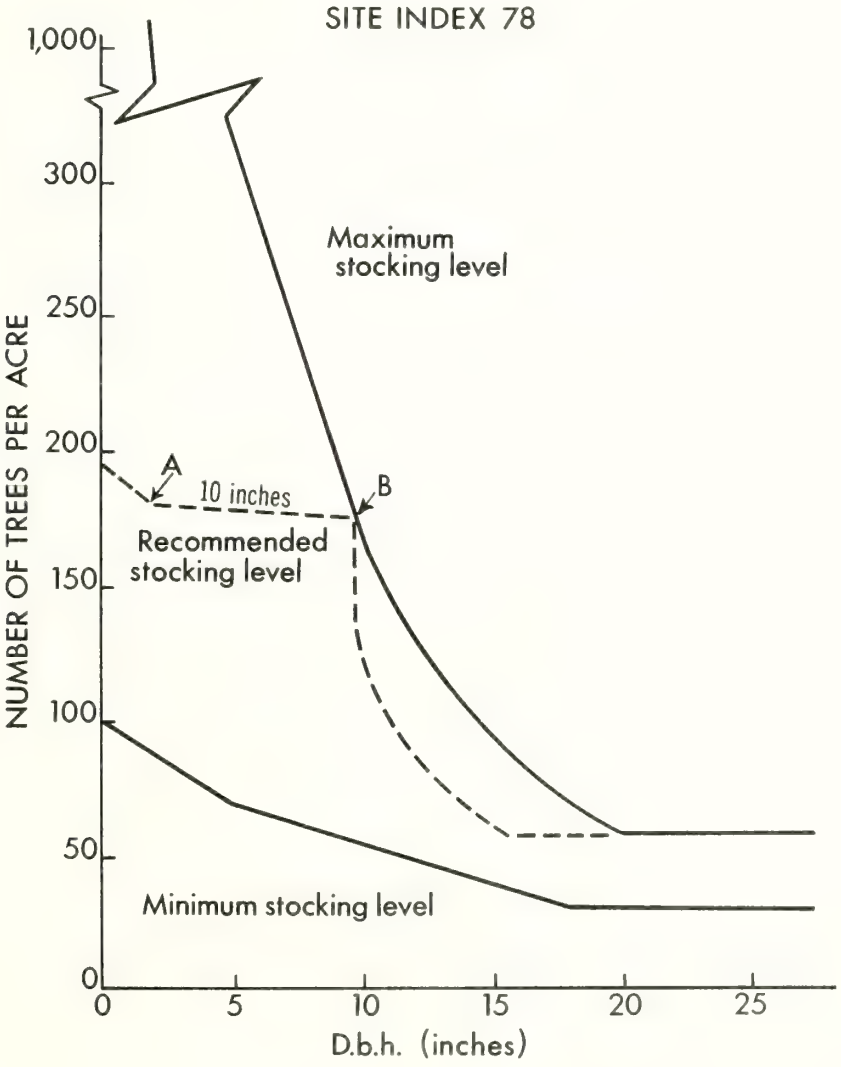


*Figure 3.--Stocking level curves for Pacific Northwest ponderosa pine.*

Current NFS stocking guides suggest that stand density in overstocked sapling stands be reduced to create open stands (fig. 4) with eventual benefits to other resources such as wildlife, watershed, and domestic meat production. The basic wood growth rationale for these stocking levels is that the stands of released trees remain open and growing at an acceptable rate, without incurring the expense of a second precommercial thinning, until the stand averages 10 inches in d.b.h. and a commercial thinning is possible (fig. 5). Fewer, but larger, trees are produced since all growth following the precommercial thinning accrues on stems that will be commercially harvested, except for a small amount of mortality.

*Figure 4.--Ponderosa pine stand 3 years after precommercial thinning.*

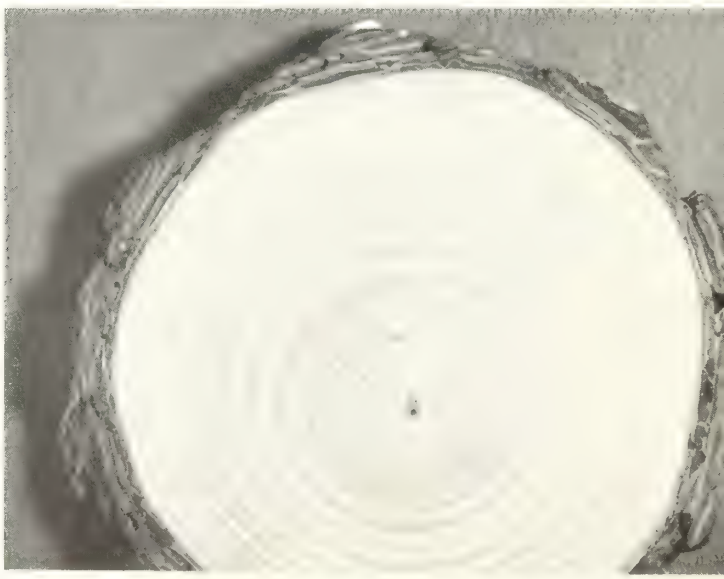

*Figure 5.--Cross-section of a released ponderosa pine tree 10 years after thinning.*

## YIELD ESTIMATES AND ASSUMPTIONS

Growth observations of ponderosa pine stands with various densities in Region 6 and research data from the Pacific Northwest Forest and Range Experiment Station (Barrett 1973) are the basis for yield projections used in the development of the precommercial thinning guides. Pertinent yield tables are included in appendix A.

Yields were developed for a stand left unthinned and for stands thinned to NFS recommended levels with an average leave tree diameter of 2, 4, 6, and 8 inches in d.b.h. on a high site (site index 78 (Meyer 1961), 100-year basis). For example (appendix A), a sapling stand with an average diameter of 1.5 inches before thinning is thinned to 180 trees, averaging 2 inches in d.b.h. and 12 feet in height, per acre. Although the stand may actually be 50, 60, or even 80 years old, the stand is given an adjusted age of 13 years in the yield table because the tree's dimensions are similar to a natural or planted tree growing without serious competition. Similarly, the 4-inch crop trees are given an adjusted age of 22 years. Periodic existing volumes plus volumes harvested by commercial thinning are accumulated by the computer program "Managed Yield" (MGYLD).[7/] The generated managed yield periodic volume increments were compared with periodic gross increments calculated from USDA Bulletin 630 to see if periodic height and diameter increments used as input for MGYLD were reasonable. The assumption here was that gross increment (net increment plus mortality) from Bulletin 630 represents a rough approximation of the potential of the site to produce wood.

Yields for a low site were estimated for the above described high site with a 2- to 4-year lag. Differences in gross yield from USDA Bulletin 630 between site indexes 70 and 78 were the basis for the lag. The effect of crop tree vigor is included in yield projections because past studies (Barrett 1969) and recent stand examinations have shown that vigor, although somewhat subjective, is a useful characteristic in judging the growth potential of ponderosa pine trees. Basic yield data assume high crop tree vigor; however, a second level, medium vigor, was recognized. Yield for medium vigor stands was assumed to be the same as for high vigor stands except for a 5-year time lag. A field guide to help distinguish the two levels of crop tree vigor is presented in table 3. Basic yield tables are presented for high site. These tables are then adjusted, as described above, to estimate yields for low site and medium vigor.

In each of the five yield projections, the first commercial harvest is made when the stand approaches

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[7/] Developed by U.S. Forest Service, Division of Timber Management, Region 6, Portland, Oregon.

95 square feet of basal area and stems average 10 inches in d.b.h. Two subsequent intermediate harvests occur at 20-year intervals. Each reduces basal area to 70 to 80 square feet.

Although yield estimates extend beyond 200 years, yields for all thinning alternatives were compared when the stand attained 22 inches in d.b.h., which closely correlates with culmination of mean annual increment of merchantable cubic feet.

Yields from the unthinned stand reflect the mortality caused by the mountain pine beetle. When basal area is more than 150 square feet per acre and d.b.h. is 8 to 12 inches, conditions are right for a beetle attack that can quickly reduce basal area on average and poor sites (Sartwell and Stevens 1975). Note in this yield table that basal area is reduced substantially from age 55 to 80 years by this insect. Thus, the growing stock base in the unthinned stand is drastically reduced and yields, as a consequence, are consistently less for a given age than in the thinned stand. After a beetle attack, trees escaping the onslaught are released and they respond to the additional growing space. The stand eventually produces notable periodic increments. Total harvested volumes are not substantially different between stands that were and were not precommercially thinned (table 5); however, the timing of the commercial thinnings and the final harvest (at the target diameter of 22 inches) is delayed as shown in table 6. Without precommercial thinning, it takes more than three and one half times as long (87 versus 24 years) to reach the first commercial thinning as it does for a precommercially thinned stand with 2-inch (d.b.h.) crop trees.

In the development of the thinning guides, all yields were reduced by 10 percent to allow for naturally occurring nonstocked holes in the stand. Yields listed in appendix A reflect 100-percent stocking.

Table 5--*Volume harvested in commercial thinnings and final harvest in an overstocked stand and in precommercially thinned stands, with an assumed 90-percent stocking*

| Precommercial thinning | Diameter at breast height of crop trees after precommercial thinning | Volume harvested | | | | |
|---|---|---|---|---|---|---|
| | | Commercial thinning | | | Final harvest[1/] | Total |
| | | 1 | 2 | 3 | | |
| | Inches | Board feet per acre | | | | |
| No | -- | 2,210 | 2,688 | 2,792 | 21,383 | 29,073 |
| Yes | 2 | 1,324 | 2,891 | 3,440 | 21,980 | 29,635 |
| Yes | 4 | 1,427 | 2,254 | 2,859 | 22,131 | 28,671 |
| Yes | 6 | 1,863 | 2,595 | 3,038 | 22,978 | 30,474 |
| Yes | 8 | 1,815 | 2,533 | 2,955 | 23,816 | 31,119 |

[1/] Final harvest target diameter is 22 inches for all stands.

Table 6--*Timing of commercial thinnings and final harvests in an overstocked stand and a precommercially thinned stand with 2-inch crop trees*

| Precommercial thinning | Years elapsed since precommercial thinning | | | |
|---|---|---|---|---|
| | Commercial thinning | | | Final harvest[1/] |
| | 1 | 2 | 3 | |
| Yes | 24 | 47 | 67 | 114 |
| No | 87 | 107 | 127 | 201 |

[1/] Final harvest target diameter is 22 inches for both stands.

## Investment Analysis

The financial thinning guides are based on an application of marginal investment analysis to the precommercial thinning decision involving ponderosa pine stands. The decision to thin an overstocked stand hinges on the net financial returns expected from the thinning operation. Only the measurable benefits and costs associated with investments in precommercial thinning are considered. The cost of thinning, including slash treatment for fire protection, esthetics, movement of wildlife and domestic animals, etc., and the value of the additional timber yields expected from the thinned stand are relevant to our analysis. Costs incurred prior to the precommercial thinning are, however, fixed costs that have no bearing on the thinning alternative selection process.

Unmarketed nontimber benefits and opportunity costs of precommercial thinning were not considered in the development of the thinning guides even though such costs are often associated with precommercial thinning.[8/] Esthetics (and its enhancement) is an example. Daniel and Boster (1976) reported that managed, relatively open forests are preferred by the public to ponderosa pine thickets--a common natural phenomenon in ponderosa pine reproduction. Therefore, unmarketed benefits and opportunity costs that are apparent, but presently unmeasurable in financial terms, should be recognized in the decisionmaking process. Consequently, the thinning priority of a low ranking (financial) alternative may be elevated because of unusual unmarketed benefits, or vice versa.

[8/] Unmarketed benefits and opportunity costs, such as adverse impacts on wildlife habitat, have an implied economic value which is often evident by the expense many people will incur to view forest scenery and the diminishing wildlife populations. How to estimate their economic value, express it in financial terms, and incorporate it into the analysis is a problem that has not been resolved.

## DISCUSSION

In the introduction we outlined two reasons why the financial thinning guides are valuable to forest managers. One reason concerned the allocation of funds among precommercial thinning opportunities. The other dealt with the consistency of the approach (within the Northwest region) to the selection of overstocked ponderosa pine stands for precommercial thinning. In this section we discuss some financial implications of investing funds in precommercial thinning operations. This will help potential users to more fully understand the guides and the rationale behind their use as a tool for ranking investment opportunities among precommercial thinning alternatives.

Tables 5 and 6 show the impact that precommercial thinning of overstocked ponderosa pine sapling stands has on the volume and the timing of commercial thinnings, the final harvest, and the total volume harvested. The most meaningful financial impact on the management of these stands results from the timing of the commercial thinnings. Table 6 indicates that in a stand of ponderosa pine with 2-inch crop trees, the first commercial thinning occurs 24 years after the precommercial thinning. If the stand is not precommercially thinned, 87 years elapse from the time the stand was considered for precommercial thinning until the stand is ready to be commercially thinned. Even though the first commercial thinning is smaller in the precommercially thinned stand (1,324 vs. 2,210 board feet), it has a much larger present value ($12.32 vs. $0.95, shown in table 1) because it occurs much sooner. The economic principle of discounting accounts for the importance of the time element. For example, if the stumpage price for commercial thinnings is $30 per thousand board feet, the revenue expected from the first commercial thinning in the above described 2-inch stand, 24 years from now, is $39.72, and its present value is $12.32. Whereas, the first commercial thinning 87 years from now in the unthinned stand will generate revenues of $66.30, but its present value is only $0.95. A 5-percent discount rate is assumed here.

Care must be exercised in the assignment of the combined precommercial thinning costs and slash treatment costs to each potential thinning opportunity. It is likely that the combined precommercial thinning and slash treatment costs will be greater for the larger d.b.h. classes because of greater slash treatment expenses. It is inappropriate, however, to generalize about the thinning guides. One must consider each thinning alternative as a separate event and rank the alternative only after calculating their B/C's and recording them as illustrated in table 4.

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## APPENDIX A

Yield Per Acre of Ponderosa Pine without Precommercial Thinning, Site Index 78

| Stand characteristics | | | | | | | | | Intermediate harvests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stand age | Number of trees | Average diameter at breast height[1/] | Average height | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top | Total volume[2/] | Mean annual increment[3/] | Number of trees | Average diameter at breast height[1/] | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top |
| Years | | Inches | Feet | Square feet | Cubic feet | Board feet | Board feet | Cubic feet | | Inches | Square feet | Cubic feet | Board feet |
| 13 | 900+ | 1.5 | 12 | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | 900+ | 2.9 | 23 | 44 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 32 | 900+ | 4.2 | 31 | 92 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | 900+ | 5.3 | 40 | 145 | 1,833 | -- | -- | 43 | -- | -- | -- | -- | -- |
| 55 | 900+ | 6.1 | 46 | 192 | 2,841 | -- | -- | 52 | -- | -- | -- | -- | -- |
| 80 | 304 | 8.3 | 57 | 114 | 941 | -- | -- | 12 | -- | -- | -- | -- | -- |
| 100 | 184 | 10.0 | 62 | 100 | 1,756 | 6,515 | 6,515 | 18 | 50 | 11.0 | 33 | 626 | 2,455 |
| 120 | 120 | 12.0 | 71 | 94 | 2,097 | 8,959 | 11,414 | 23 | 40 | 12.0 | 31 | 699 | 2,986 |
| 140 | 76 | 14.8 | 79 | 91 | 2,356 | 11,314 | 16,756 | 26 | 22 | 14.5 | 25 | 652 | 3,102 |
| 160 | 52 | 17.4 | 84 | 86 | 2,409 | 12,292 | 20,835 | 27 | -- | -- | -- | -- | -- |
| 180 | 52 | 19.4 | 90 | 107 | 3,185 | 17,156 | 25,700 | 29 | -- | -- | -- | -- | -- |
| 200 | 52 | 21.1 | 94 | 126 | 3,917 | 21,774 | 30,317 | 29 | -- | -- | -- | -- | -- |
| 220 | 52 | 22.4 | 98 | 140 | 4,382 | 24,610 | 33,153 | 29 | -- | -- | -- | -- | -- |
| 240 | 52 | 23.3 | 100 | 148 | 4,730 | 26,892 | 35,436 | 28 | -- | -- | -- | -- | -- |

[1/] Average diameter of all trees.

[2/] Scribner volume to a 6-inch top.

[3/] Merchantable volume to a 6-inch top.

Yield Per Acre of Ponderosa Pine with Precommercial Thinning, 2-Inch Leave Tree Diameter, Site Index 78

| Stand characteristics | | | | | | | | | Intermediate harvests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stand age | Number of trees | Average diameter at breast height[1] | Average height | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top | Total volume[2] | Mean annual increment[3] | Number of trees | Average diameter at breast height[1] | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top |
| Years | | Inches | Feet | Square feet | Cubic feet | Board feet | Board feet | Cubic feet | | Inches | Square feet | Cubic feet | Board feet |
| 13 | 900+ | 1.5 | 12 | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | 175 | 10.0 | 38 | 95 | 1,130 | 3,913 | 3,913 | 31 | 48 | 11.0 | 32 | 402 | 1,471 |
| 60 | 124 | 13.0 | 56 | 114 | 2,253 | 9,715 | 11,185 | 44 | 41 | 13.0 | 38 | 745 | 3,212 |
| 80 | 81 | 16.1 | 68 | 114 | 2,735 | 13,112 | 17,794 | 48 | 24 | 16.0 | 34 | 800 | 3,822 |
| 100 | 56 | 18.8 | 78 | 108 | 2,888 | 15,031 | 23,536 | 48 | -- | -- | -- | -- | -- |
| 120 | 56 | 21.3 | 86 | 139 | 4,019 | 22,046 | 30,551 | 50 | -- | -- | -- | -- | -- |
| 140 | 56 | 23.4 | 94 | 167 | 5,095 | 28,837 | 37,342 | 50 | -- | -- | -- | -- | -- |
| 160 | 54 | 24.9 | 100 | 183 | 5,850 | 33,870 | 42,375 | 49 | -- | -- | -- | -- | -- |
| 180 | 53 | 25.9 | 106 | 194 | 6,511 | 38,555 | 47,060 | 47 | -- | -- | -- | -- | -- |
| 200 | 52 | 26.7 | 110 | 202 | 6,999 | 41,918 | 50,423 | 45 | -- | -- | -- | -- | -- |
| 220 | 51 | 27.4 | 113 | 209 | 7,390 | 44,586 | 53,092 | 42 | -- | -- | -- | -- | -- |

[1] Average diameter of all trees.

[2] Scribner volume to a 6-inch top.

[3] Merchantable volume to a 6-inch top.

Yield Per Acre of Ponderosa Pine with Precommercial Thinning, 4-Inch Leave Tree Diameter, Site Index 78

| Stand characteristics | | | | | | | | | Intermediate harvests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stand age | Number of trees | Average diameter at breast height[1] | Average height | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top | Total volume[2] | Mean annual increment[3] | Number of trees | Average diameter at breast height[1] | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top |
| Years | | Inches | Feet | Square feet | Cubic feet | Board feet | Board feet | Cubic feet | | Inches | Square feet | Cubic feet | Board feet |
| 22 | 900+ | 2.9 | 23 | 44 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | 175 | 10.0 | 42 | 95 | 1,202 | 4,247 | 4,247 | 28 | 48 | 11.0 | 32 | 430 | 1,586 |
| 60 | 124 | 12.2 | 55 | 101 | 1,924 | 7,963 | 9,549 | 39 | 41 | 12.0 | 32 | 612 | 2,504 |
| 80 | 81 | 15.3 | 67 | 103 | 2,427 | 11,275 | 15,365 | 43 | 24 | 15.0 | 30 | 689 | 3,177 |
| 100 | 56 | 18.1 | 77 | 100 | 2,644 | 13,604 | 20,870 | 44 | -- | -- | -- | -- | -- |
| 120 | 56 | 20.4 | 85 | 127 | 3,645 | 19,666 | 26,933 | 45 | -- | -- | -- | -- | -- |
| 140 | 56 | 22.5 | 93 | 155 | 4,664 | 26,129 | 33,396 | 46 | -- | -- | -- | -- | -- |
| 160 | 54 | 24.0 | 99 | 170 | 5,385 | 30,780 | 38,046 | 44 | -- | -- | -- | -- | -- |
| 180 | 53 | 25.0 | 105 | 181 | 6,014 | 35,258 | 42,525 | 43 | -- | -- | -- | -- | -- |
| 200 | 52 | 25.8 | 109 | 189 | 6,480 | 38,495 | 45,762 | 41 | -- | -- | -- | -- | -- |
| 220 | 51 | 26.5 | 112 | 195 | 6,857 | 41,077 | 48,344 | 39 | -- | -- | -- | -- | -- |

[1] Average diameter of all trees.

[2] Scribner merchantable volume to a 6-inch top.

[3] Merchantable volume to a 6-inch top.

Yield Per Acre of Ponderosa Pine with Precommercial Thinning, 6-Inch Leave Tree Diameter, Site Index 78

| Stand characteristics | | | | | | | | | Intermediate harvests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stand age | Number of trees | Average diameter at breast height[1] | Average height | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top | Total volume[2] | Mean annual increment[3] | Number of trees | Average diameter at breast height[1] | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top |
| Years | | Inches | Feet | Square feet | Cubic feet | Board feet | Board feet | Cubic feet | | Inches | Square feet | Cubic feet | Board feet |
| 32 | 900+ | 4.2 | 31 | 93 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 50 | 175 | 10.0 | 46 | 95 | 1,452 | 5,526 | 5,526 | 29 | 50 | 11.0 | 33.0 | 533 | 2,070 |
| 70 | 122 | 12.2 | 64 | 99 | 2,131 | 9,215 | 11,286 | 38 | 40 | 12.0 | 31.4 | 671 | 2,883 |
| 90 | 80 | 15.1 | 74 | 100 | 2,496 | 11,947 | 16,900 | 41 | 23 | 15.0 | 23.2 | 707 | 3,375 |
| 120 | 56 | 18.6 | 82 | 106 | 2,930 | 15,217 | 23,545 | 40 | -- | -- | -- | -- | -- |
| 140 | 56 | 19.9 | 90 | 121 | 3,616 | 19,634 | 27,962 | 40 | -- | -- | -- | -- | -- |
| 160 | 56 | 22.4 | 96 | 153 | 4,736 | 26,572 | 34,899 | 40 | -- | -- | -- | -- | -- |
| 180 | 54 | 23.4 | 102 | 161 | 5,234 | 29,959 | 38,236 | 40 | -- | -- | -- | -- | -- |
| 200 | 53 | 24.2 | 106 | 169 | 5,671 | 33,039 | 41,367 | 38 | -- | -- | -- | -- | -- |
| 220 | 52 | 25.4 | 109 | 183 | 6,277 | 37,162 | 45,489 | 33 | -- | -- | -- | -- | -- |

[1] Average diameter of all trees.

[2] Scribner merchantable volume to a 6-inch top.

[3] Merchantable volume to a 6-inch top.

Yield Per Acre of Ponderosa Pine with Precommercial Thinning, 8-Inch Leave Tree Diameter, Site Index 78

| Stand characteristics | | | | | | | | | Intermediate harvests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stand age | Number of trees | Average diameter at breast height[1/] | Average height | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top | Total volume[2/] | Mean annual increment[3/] | Number of trees | Average diameter at breast height[1/] | Basal area | Merchantable volume to a 6-inch top | Scribner volume to a 6-inch top |
| Years | | Inches | Feet | Square feet | Cubic feet | Board feet | Board feet | Cubic feet | | Inches | Square feet | Cubic feet | Board feet |
| 45 | 900+ | 5.3 | 40 | 153 | 1,930 | -- | -- | 43 | -- | -- | -- | -- | -- |
| 60 | 175 | 10.0 | 48 | 95 | 1,479 | 5,610 | 5,610 | 25 | 48 | 11.0 | 32 | 523 | 2,017 |
| 80 | 124 | 12.4 | 62 | 104 | 2,205 | 9,577 | 11,594 | 34 | 40 | 12.0 | 31 | 658 | 2,814 |
| 100 | 82 | 15.0 | 72 | 101 | 2,474 | 11,706 | 16,537 | 37 | 23 | 15.0 | 28 | 694 | 3,284 |
| 120 | 58 | 17.5 | 80 | 97 | 2,623 | 13,401 | 21,515 | 37 | -- | -- | -- | -- | -- |
| 140 | 58 | 19.6 | 88 | 122 | 3,567 | 19,179 | 27,294 | 39 | -- | -- | -- | -- | -- |
| 160 | 58 | 21.2 | 94 | 142 | 4,411 | 24,554 | 32,668 | 39 | -- | -- | -- | -- | -- |
| 180 | 56 | 22.3 | 100 | 152 | 4,843 | 27,178 | 35,293 | 37 | -- | -- | -- | -- | -- |
| 200 | 55 | 23.1 | 106 | 160 | 5,351 | 30,801 | 38,916 | 36 | -- | -- | -- | -- | -- |
| 220 | 54 | 23.9 | 110 | 168 | 5,800 | 33,893 | 42,008 | 35 | -- | -- | -- | -- | -- |

1/ Average diameter of all trees.

2/ Scribner volume to a 6-inch top.

3/ Merchantable volume to a 6-inch top.

## APPENDIX B[1/]

2. Overstory Removal. The need for an overstory removal occurs both from a previously executed shelterwood harvest or seed cut and also frequently results from natural causes such as insects, disease, etc. The following priorities apply without distinction as to how the stand was created:

Priorities:

a. Lightly-Stocked Damaged Overwood with Established Understory.
Live, sound crop tree stocking level is at or above the recommended level and crop trees are considered established, i.e. at least 4-1/2 feet tall, but less than pole size. The mature overstory is below minimum stocking level and trees are in poor condition, dead, dying, or diseased such as mistletoe. Dwarf mistletoe should be evaluated as indicated in FSM 5261, Dwarf Mistletoe Control.

b. Lightly-Stocked Healthy Overwood with Established Understory.
Live, sound crop tree stocking level is at or above the recommended level and crop trees are considered established, i.e. at least 4-1/2 feet tall, but less than pole size. The mature overstory is below minimum stocking level, trees are healthy, and are no longer needed for shade.

c. Lightly-Stocked Overwood with above Minimum Stocking Underwood.
Live, sound crop tree stocking level is below the recommended level but above the minimum level and crop trees are established as above. The mature overstory is below minimum stocking level and trees are not needed for shade or additional seed.-*

*-d. Lightly-Stocked Poor Vigor Overwood with Pole Understory.
Live, sound crop tree stocking level is above the minimum level and crop trees are pole size. Mature trees are below minimum stocking level, of poor thrift, and likely will die before the stand is scheduled for a regeneration cut.

e. Lightly-Stocked Poor Vigor Overwood with Commercial Thinning Size Underwood.
Live, sound crop tree stocking level is above the minimum level and crop trees are of a merchantable size. Mature trees are below minimum stocking level, of poor thrift. Evaluate whether or not mature trees will survive until a regeneration cut is scheduled for the crop trees. If mature trees will last, do not schedule overstory removal.

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1/ From "Silvicultural Examination and Prescription Handbook," Region 6, Forest Service, U.S. Department of Agriculture, Portland, Oregon, 1974.

A F

ECONOMIC PRECOMMERCIAL THINNING GUIDES FOR N

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FOR 2-INCH CROP TREES

| Precommercial thinning cost ($/acre) | | | | | | |
|---|---|---|---|---|---|---|
| | High site - high vigor | | | | | |
| 100 | 0.27 | 0.54 | 0.80 | 1.07 | 1.34 | 1.61 |
| 75 | .36 | .71 | 1.07 | 1.43 | 1.78 | 2.14 |
| 50 | .54 | 1.07 | 1.61 | 2.14 | 2.68 | 3.21 |
| 25 | 1.07 | 2.14 | 3.21 | 4.28 | 5.35 | 6.42 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | | |
| | High site - medium vigor | | | | | |
| 100 | .21 | .42 | .63 | .84 | 1.05 | 1.26 |
| 75 | .28 | .56 | .84 | 1.12 | 1.40 | 1.68 |
| 50 | .42 | .84 | 1.26 | 1.68 | 2.10 | 2.52 |
| 25 | .84 | 1.67 | 2.52 | 3.35 | 4.20 | 5.03 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | | |
| | Low site - high vigor | | | | | |
| 100 | .19 | .39 | .58 | .78 | .97 | 1.17 |
| 75 | .26 | .52 | .78 | 1.04 | 1.30 | 1.56 |
| 50 | .39 | .78 | 1.17 | 1.56 | 1.95 | 2.33 |
| 25 | .78 | 1.56 | 2.33 | 3.11 | 3.89 | 4.67 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | | |
| | Low site - medium vigor | | | | | |
| 100 | .15 | .30 | .46 | .61 | .76 | .91 |
| 75 | .20 | .41 | .61 | .81 | 1.02 | 1.22 |
| 50 | .30 | .61 | .91 | 1.22 | 1.52 | 1.83 |
| 25 | .61 | 1.22 | 1.83 | 2.44 | 3.05 | 3.66 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | | |

FOR 4-INCH CROP TREES

| Precommercial thinning cost ($/acre) | | | | | |
|---|---|---|---|---|---|
| | High site - high vigor | | | | |
| 100 | 0.32 | 0.64 | 0.96 | 1.28 | 1.60 |
| 75 | .43 | .86 | 1.28 | 1.71 | 2.14 |
| 50 | .64 | 1.28 | 1.93 | 2.57 | 3.21 |
| 25 | 1.28 | 2.57 | 3.85 | 5.14 | 6.42 |
| | 40 | 80 | 120 | 160 | 200 |
| | Stumpage (dollars per thou board feet) | | | | |
| | High site - medium vigor | | | | |
| 100 | .25 | .50 | .75 | 1.01 | 1.26 |
| 75 | .34 | .67 | 1.01 | 1.34 | 1.68 |
| 50 | .50 | 1.01 | 1.51 | 2.01 | 2.52 |
| 25 | 1.01 | 2.01 | 3.02 | 4.02 | 5.03 |
| | 40 | 80 | 120 | 160 | 200 |
| | Stumpage (dollars per thou board feet) | | | | |
| | Low site - high vigor | | | | |
| 100 | .25 | .49 | .74 | .99 | 1.24 |
| 75 | .33 | .66 | .99 | 1.32 | 1.65 |
| 50 | .49 | .99 | 1.48 | 1.98 | 2.47 |
| 25 | .99 | 1.98 | 2.97 | 3.96 | 4.95 |
| | 40 | 80 | 120 | 160 | 200 |
| | Stumpage (dollars per thou board feet) | | | | |
| | Low site - medium vigor | | | | |
| 100 | .19 | .39 | .58 | .77 | .97 |
| 75 | .26 | .52 | .77 | 1.03 | 1.29 |
| 50 | .39 | .77 | 1.16 | 1.55 | 1.94 |
| 25 | .77 | 1.55 | 2.32 | 3.10 | 3.87 |
| | 40 | 80 | 120 | 160 | 200 |
| | Stumpage (dollars per thou board feet) | | | | |

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A PINE STANDS EXPRESSED IN BENEFIT/COST RATIOS

rate)

FOR 6-INCH CROP TREES

| | High site - high vigor | | | | | |
|---|---|---|---|---|---|---|
| 0.19 | 0.39 | 0.58 | 0.78 | 0.97 | 1.16 |
| .22 | .44 | .67 | .89 | 1.11 | 1.33 |
| .26 | .52 | .78 | 1.03 | 1.29 | 1.55 |
| .31 | .62 | .93 | 1.24 | 1.55 | 1.86 |
| .39 | .78 | 1.16 | 1.55 | 1.94 | 2.33 |
| .52 | 1.03 | 1.55 | 2.07 | 2.59 | 3.10 |
| 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | |
| | High site - medium vigor | | | | |
| .15 | .30 | .46 | .61 | .76 | .91 |
| .17 | .35 | .52 | .69 | .87 | 1.04 |
| .20 | .41 | .61 | .81 | 1.01 | 1.22 |
| .24 | .49 | .73 | .97 | 1.22 | 1.46 |
| .30 | .61 | .91 | 1.22 | 1.52 | 1.82 |
| .41 | .81 | 1.22 | 1.62 | 2.03 | 2.43 |
| 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | |
| | Low site - high vigor | | | | |
| .16 | .31 | .47 | .62 | .78 | .93 |
| .18 | .36 | .53 | .71 | .89 | 1.07 |
| .21 | .42 | .62 | .83 | 1.04 | 1.25 |
| .25 | .50 | .75 | 1.00 | 1.25 | 1.50 |
| .31 | .62 | .93 | 1.25 | 1.56 | 1.87 |
| .42 | .83 | 1.25 | 1.66 | 2.08 | 2.49 |
| 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | |
| | Low site - medium vigor | | | | |
| .12 | .24 | .37 | .49 | .61 | .73 |
| .14 | .28 | .42 | .56 | .70 | .84 |
| .16 | .33 | .49 | .65 | .81 | .98 |
| .20 | .39 | .59 | .78 | .98 | 1.47 |
| .24 | .49 | .73 | .98 | 1.22 | 1.46 |
| .33 | .65 | .98 | 1.30 | 1.63 | 1.95 |
| 40 | 80 | 120 | 160 | 200 | 240 |
| | Stumpage (dollars per thousand board feet) | | | | |

FOR 8-INCH CROP TREES

| Precommercial thinning cost ($/acre) | High site - high vigor | | | | | |
|---|---|---|---|---|---|---|
| 200 | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 | 1.20 |
| 175 | .23 | .46 | .69 | .92 | 1.14 | 1.37 |
| 150 | .27 | .53 | .80 | 1.07 | 1.34 | 1.60 |
| 125 | .32 | .64 | .96 | 1.28 | 1.60 | 1.92 |
| 100 | .40 | .80 | 1.20 | 1.60 | 2.00 | 2.40 |
| 75 | .53 | 1.07 | 1.60 | 2.14 | 2.67 | 3.20 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | | Stumpage (dollars per thousand board feet) | | | | |
| | High site - medium vigor | | | | | |
| 200 | .16 | .31 | .47 | .63 | .78 | .94 |
| 175 | .18 | .36 | .54 | .72 | .90 | 1.07 |
| 150 | .21 | .42 | .63 | .84 | 1.05 | 1.26 |
| 125 | .25 | .50 | .75 | 1.00 | 1.26 | 1.51 |
| 100 | .31 | .63 | .94 | 1.26 | 1.57 | 1.88 |
| 75 | .42 | .84 | 1.26 | 1.67 | 2.09 | 2.51 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | | Stumpage (dollars per thousand board feet) | | | | |
| | Low site - high vigor | | | | | |
| 200 | .17 | .35 | .52 | .69 | .86 | 1.04 |
| 175 | .20 | .39 | .59 | .79 | .99 | 1.18 |
| 150 | .23 | .46 | .69 | .92 | 1.15 | 1.38 |
| 125 | .28 | .55 | .83 | 1.11 | 1.38 | 1.66 |
| 100 | .35 | .69 | 1.04 | 1.38 | 1.73 | 2.07 |
| 75 | .46 | .92 | 1.38 | 1.84 | 2.30 | 2.76 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | | Stumpage (dollars per thousand board feet) | | | | |
| | Low site - medium vigor | | | | | |
| 200 | .14 | .27 | .41 | .54 | .68 | .81 |
| 175 | .15 | .31 | .46 | .62 | .77 | .93 |
| 150 | .18 | .36 | .54 | .72 | .90 | 1.08 |
| 125 | .22 | .43 | .65 | .87 | 1.08 | 1.30 |
| 100 | .27 | .54 | .81 | 1.08 | 1.35 | 1.62 |
| 75 | .36 | .72 | 1.08 | 1.44 | 1.81 | 2.17 |
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | | Stumpage (dollars per thousand board feet) | | | | |

Sassaman, Robert W., James W. Barrett, and Asa D. Twombly. 1977. Financial precommercial thinning guides for Northwest ponderosa pine stands. USDA For. Serv. Res. Pap. PNW-226, 27 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This paper describes a flexible management tool designed to be applicable to thinning alternatives for an infinite number of combinations of crop tree size and vigor, site quality, thinning costs, stumpage prices, and three discount rates.

KEYWORDS: Precommercial thinning, thinning (precommercial), improvement cutting, forestry business economics, economics (forestry business), site class, diameter increment, increment (diameter), stumpage prices, cost and return accounting (forestry), timber management planning, ponderosa pine, *Pinus ponderosa*, Pacific Northwest.

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USDA FOREST SERVICE RESEARCH PAPER PNW-227
1977

# Quantitative Geomorphic Approach to Predicting Productivity of Pink and Chum Salmon Streams in Southeast Alaska

AUTHENTIC
TLINGIT INDIAN
FISH CHARM

Douglas N. Swanston
William R. Meehan
James A. McNutt

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
US DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

# A Quantitative Geomorphic Approach to Predicting Productivity of Pink and Chum Salmon Streams in Southeast Alaska


*Reference Abstract*

Swanston, Douglas N., William R. Meehan, and James A. McNutt. 1977. A quantitative geomorphic approach to predicting productivity of pink and chum salmon streams in southeast Alaska. USDA For. Serv. Res. Pap. PNW-227, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Twenty-one quantitative geomorphic variables, measured from aerial photographs and topographic and geologic maps of 78 watersheds, were tested for significance in differentiating between good and poor producers of pink and chum salmon. A discriminant model was then constructed. Using this model, the decisionmaker can make a qualititative estimate of potential pink and chum salmon production for any southeast Alaska watershed with minimum field investigation.



KEYWORDS: Fish management, geomorphology, salmonids, Alaska (southeast).


*RESEARCH SUMMARY*

*Research Paper PNW–227*

*1977*

Salmon streams in southeast Alaska vary in the amount of fish they produce per usable area of stream. What this variability is and how a particular stream may be rated qualitatively with respect to others in terms of productivity are of considerable concern to the forest land manager at the planning level.

To provide a simple tool for making such assessments, 21 quantitative geomorphic variables were measured from air photos and topographic and geologic maps of 78 watersheds identified as either exceptionally good or exceptionally poor pink and chum salmon producers. Each of these variables was tested for significance in differentiating between good and poor producers. A discriminant model was then constructed using the eight most significant variables. Each of these variables is easily obtainable from air photos and topographic maps with minimal amounts of fieldwork. Together the variables provide a linear equation yielding a qualitative estimate of potential pink and chum salmon production for any southeast Alaska stream.

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## Introduction

Salmon streams in southeast Alaska vary in amount of salmon produced per usable area. In many cases, the factors that limit production in some streams are readily discernible: overfishing, barriers to fish passage (falls, logjams), unfavorable streambed conditions (sedimentation, unstable gravel beds), excessive gradient, and highly variable streamflow. In some cases, however, streams that appear to have favorable conditions for salmon production do not support runs in proportion to their apparent potential. Questions then arise: Do geomorphic factors regulate production of salmon in these streams? Are these factors, or groups of factors, discernible directly as gross watershed characteristics, or are they more subtly related to local variations in the physical, chemical, or biological makeup of individual streams? Can the productivity of a particular stream be predicted from simple measurements of watershed characteristics on aerial photographs and topographic maps, or is a detailed investigation of streams and monitoring of fish populations necessary? Answers to these questions will have considerable bearing on the management of anadromous fisheries as the potential for damage from man's activities increases and as emphasis changes from maintenance of natural stocks of salmon to increased quality and productivity of watersheds.

## Factor Identification

Thompson and Hunt (1930) stressed the importance of the drainage basin as a whole, not just the stream, in their investigations of the basic nature of stream productivity. Slack (1955) reinforced this concept in his studies of stream productivity factors, demonstrating that the biological productivity of a stream is directly related to the physical environment of the watershed, which controls drainage pattern, flow rates, gravel size and shape, channel gradient, and general stability characteristics. Statistical analysis of quantitative geomorphic parameters of individual watersheds can help identify these factors.

Quantitative geomorphic techniques developed by Horton (1932, 1945) and Strahler (1952, 1953, 1954) provide a convenient method for obtaining numerical data on gross basin characteristics, given limited funding and difficulty of access and sampling of test streams. Measurement of physical parameters based on basin and channel geometry, obtainable from aerial photographs and topographic maps, provides correlation units such as drainage size and shape, stream density, and pattern, number, and length of tributaries. These in turn provide an estimate of stage of watershed development, probable basin discharge, extent of bedrock control of drainage,

impact of unstable slopes, and extent of channel suitable for spawning. Such techniques have been used successfully to analyze relationships between erosion, climate, surface properties, and geomorphology (Melton 1957, Maxwell 1960, Dissmeyer 1967). In 1973, Ziemer used quantitative geomorphic techniques to relate drainage basin and channel configuration to changes in production of pink salmon on Montague Island, Prince William Sound, Alaska, after large vertical tectonic adjustments resulting from the "Good Friday Earthquake" of 1964. Using five drainage system factors, he showed a correlation between drainage system geometry and freshwater production factors for pink salmon, with escapement as his indicator of production. He assumed that (1) the number of spawners using a stream is a sound measure of fish production in that stream, (2) escapement counts were consistently made from year to year and stream to stream, and (3) the impact of the fishery was consistent between stocks and years. He realized the problems involved by making these assumptions, but he had no other tools available.

Several quantitative methods were considered in an attempt to assign numbers to various degrees of salmon production. Enough time could not be spent on each stream to obtain even rough estimates of the standing crop of juveniles, egg or preemergent fry densities, or some other biological measure of production. Escapement counts are available for most southeast Alaska salmon streams for many years back. These counts are summarized in a set of catalogs that describe the physical characteristics of streams as well as the number of salmon that have returned to their spawning grounds. (Catalogs can be seen at the Alaska Department of Fish and Game, Juneau). However, salmon escapement data are not necessarily a reliable index of production of a given stream. Escapement is only one portion of the total run returning to a stream--the portion that has survived the onslaught of the fishery and has successfully completed the upstream migration to the spawning grounds. Intensity of the fishing effort as well as success of fishing is not necessarily the same for different streams. Consequently, the total return (catch plus escapement) to two streams may be similar. If fishing mortality, however, has accounted for two-thirds of the total return to one stream and one-third of the total return to another stream, escapement to the second stream may be twice as great. Other factors also may produce differential survival between stocks of fish. The ocean feeding area of one population may promote better growth and/or survival than another. The migration routes of one stock may subject that run to greater predation than the route or timing of another run. Aerial and ground surveys of escapements are often conducted at different stages of a given run in different years, by various observers, under different light conditions, etc. The main point is that escapement to a stream, although it may help in *qualitatively* describing the general level of production of the stream, does not necessaril indicate the biomass of salmon

that were or could be produced in that stream. A better *quantitative* indication of a stream's fish production would be the average number of smolts (seaward migrant juveniles) produced by a known number of spawning females over several years. Obtaining this type of information for many streams is costly, time consuming and, as a result, generally not done.

For this study, streams were categorized as either good producers or poor producers of pink and chum salmon. These categories were based on interviews and correspondence with district fishery management biologists throughout southeast Alaska and on the many years of escapement data (aerial and ground surveys by several agencies) summarized in the stream catalogs. Production was not based on escapement figures alone. Streams which were thought to be fair producers were not selected, so that only *very good* production and *very poor* production of pink and chum salmon were considered. Poor producers were further defined as streams to which no known causes for poor runs could be attributed; that is, they were streams which were accessible to migrating fish throughout most of their length (not blocked by falls, logjams, etc.), they appeared to have sufficient high quality water and gravels, they were not regularly "robbed" by illegal fishing, and they had not historically supported good pink and chum salmon runs. This subjective selection of good producers and poor producers may be criticized as not being statistically valid since the streams were not a randomly selected sample of all the available streams in southeast Alaska--one person's idea of "good" or "poor" may differ greatly from that of the next. However, we felt that this type of selection was justified since we specified only very good or very poor streams and since this is the type of selection process that may be necessary for the resource manager to use when he does not have the time and funds to obtain more quantitative estimates of production.

## Data Accumulation

A total of 78 watersheds were categorized as either exceptionally good producers or exceptionally poor producers based on the preceding criteria. These watersheds were scattered throughout southeast Alaska. They ranged in size from a minimum of 5.2 $km^2$ to a maximum of 422.2 $km^2$ (fig. 1); 22 were classified as poor and 56 as good.

To identify general similarities or differences between good producers and poor producers, we selected 21 independent variables for inter-basin correlation purposes. These variables are listed in table 1. Of these, 19 were continuous--that is, they appeared at varying levels in every basin and could be simply measured on aerial photographs or 15-minute quadrangle maps. The other two were discontinuous; they classed each watershed according to whether it was underlain predominantly by igneous bedrock or metasedimentary bedrock. Of the 19 continuous variables, 14 [illegible] were

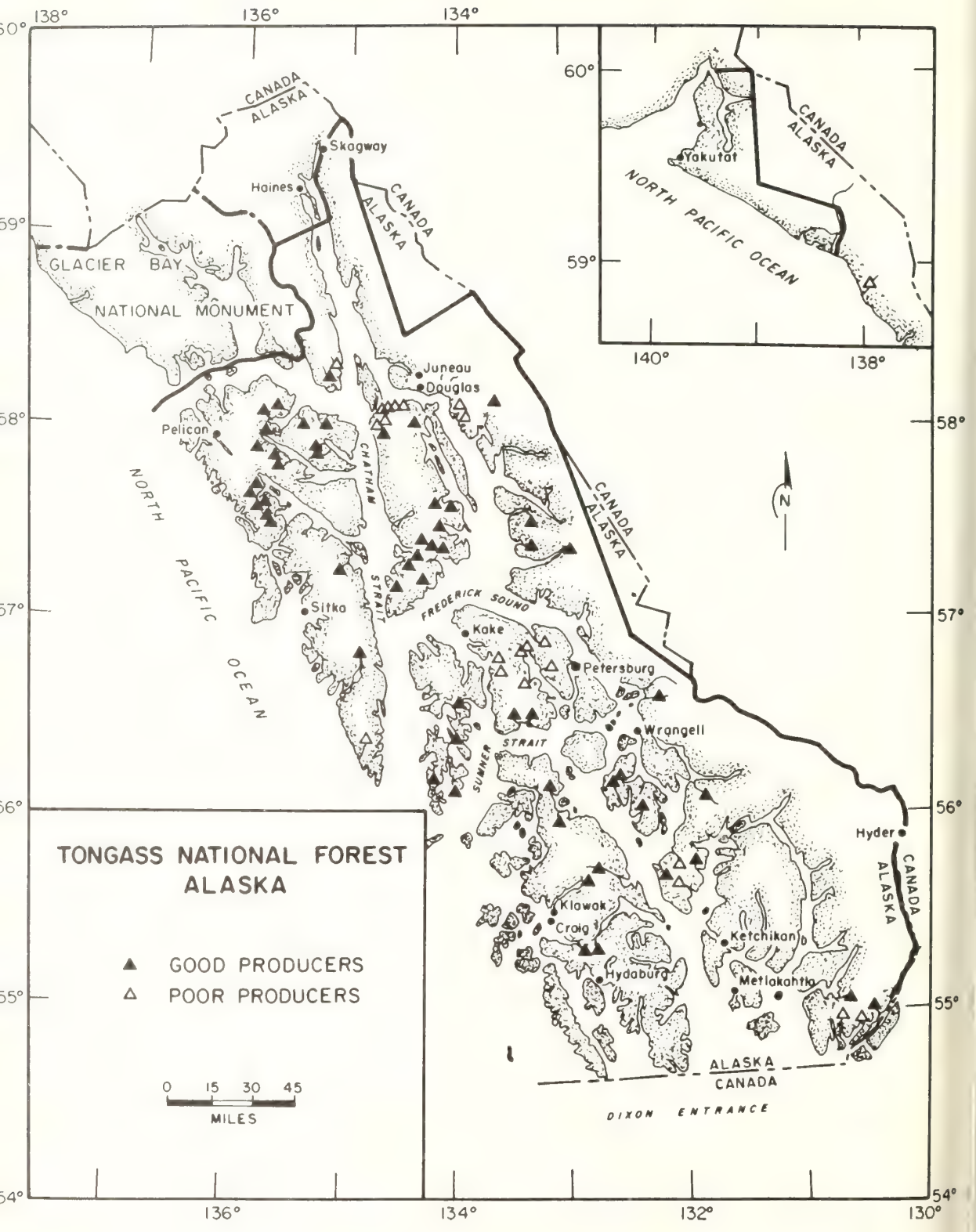


*Figure 1.--Map showing location of sample watersheds.*

Table 1--*List of quantitative geomorphic variables used for interbasin correlation purposes*

| Symbol | Variable | Unit of measurement |
|---|---|---|
| $X_1$ | Area of drainage basin | $km^2$ |
| $X_2$ | Mean valley side slope | degrees |
| $X_3$ | Basin area with slope above critical angle (34°) | percent |
| $X_4$ | Avalanche index (number of avalanches in watershed) | number |
| $X_5$ | Drainage density | dimensionless |
| $X_6$ | Bifurcation ratio | dimensionless |
| $X_7$ | Total length of channel segments | km |
| $X_8$ | Gradient of stream channel | degrees |
| $X_9$ | Length of stream with acceptable spawning gradient (<12 percent) | km |
| $X_{10}$ | Obstructions in main channel | number |
| $X_{11}$ | Basin perimeter | km |
| $X_{12}$ | Basin relief | m |
| $X_{13}$ | Channel frequency | dimensionless |
| $X_{14}$ | Relative relief | dimensionless |
| $X_{15}$ | Compactness coefficient | dimensionless |
| $X_{16}$ | Form factor | dimensionless |
| $X_{17}$ | Lakes in stream system | number |
| $X_{18}$ | Length ratio | dimensionless |
| $X_{19}$ | Basin orientation | degrees |
| $X_{20}$ | Predominatly sedimentary/ metamorphic rock (>50 percent) | 1 |
| $X_{21}$ | Predominantly igneous rock (>50 percent) | 2 |

standard quantitative geomorphic variables that provide a measure of basin or channel geometry, discharge characteristics, or stage of watershed development. Five ($X_3$, $X_4$, $X_9$, $X_{10}$, $X_{17}$) were developed for this study to provide a direct measure of basin stability and productivity.

## Analysis

The purposes of the data analysis were: (1) to test each variable for significance in differentiating between good producers and poor producers and (2) to construct a discriminant model that would give a decisionmaker or researcher the opportunity to classify salmon streams as either *very poor* producers or *very good* producers. Analysis dictated a search for a "best possible" model (where "best" is determined by trade-offs between statistical accuracy, data collection feasibility, and model application costs) that would provide more potential gain than cost to the user and that could be applied to any watershed for classifying it as a good producer or poor producer. Figure 2 shows such a model. Note that this approach requires equal dispersions for both groups but does not require equal sample sizes (Cooley and Lohnes 1971).

Data analysis was handled in four stages. Stage 1 involved computer-assisted evaluation of each explanatory variable property. This evaluation required examination of sample statistics, histograms, scatter diagrams, and correlation coefficients for each variable. Stage 2 centered on basic linear regression analysis of the 21

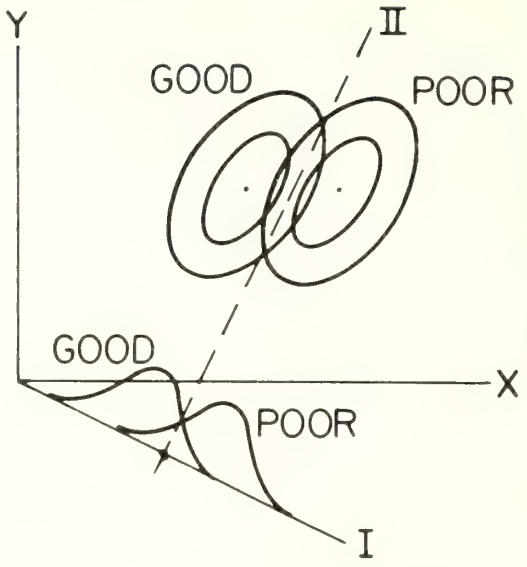


*Figure 2.--Geometric interpretation of discriminant analysis (after Cooley and Lohnes 1971, used with permission): (a) problem for two groups and two variates (x and y); (b) line I ⊥ line II; (c) elipse sets called centours for centile contours; (d) overlap of group good or poor is smaller than for any other set; (e) picture outer elipses as including 90 percent of each group and inner elipses 75 percent of each group.*

independent variables on salmon productivity. Stage 3 involved development of a family of discriminant functions from which a subset could be selected for further evaluation. Stage 4 included comparative analysis of selected key discriminant models. All analytical work was accomplished with the aid of special data processing facilities and software available through Oregon State University, Corvallis.

Stage 1 provided familiarity with the explanatory variables and all relevant interrelationships. Stage 2 provided a tool for evaluating possible model structures and behavioral characteristics. The basic approach was a "modified-backstep" regression analysis. All explanatory variables were regressed on a salmon productivity dummy variable. The least significant variables were dropped one at a time in each "backstep." At each juncture, the t-values of previously dropped variables were scanned. Any dropped variable which had a t-value that climbed back to a value of ±2.0 was reentered into the specified model. This approach allows for development of more significant models than does "stepwise regression" (Draper and Smith 1968). The reason for using regression modeling prior to using discriminant modeling is that a two-class linear, discriminant function is algebraically equivalent to a regression model. Model stability, structure, and order of variable importance (significance) are more easily examined and evaluated in a regression model than in a discriminant model; for example, for presence and impact of multicolinearity.

Stage 2 resulted in several significant models and a battery of test results that examined the reliability of six model assumptions (Kmenta 1971): (1) Error term is normally distributed, (2) expected value of the error term is zero, (3) variance of the error term is a constant, (4) error terms are not correlated in time and/or space, (5) each explanatory variable is nonstochastic, and (6) no explanatory variable has an exact linear relationship with any other explanatory variable. Examination of histograms and selected scatter diagrams of the residuals as well as of covariance matrices and correlation matrices did not indicate that any of these assumptions was violated significantly for the models considered (Draper and Smith 1968, Kmenta 1971).

Stage 3 produced a variety of discriminant models for later evaluation. The approach used in forming these models was the "modified-backstep" procedure that simply began with a fully specified model (all 21 explanatory variables) and dropped variables, one by one, in the same order as determined for the regression modeling procedure. For practical purposes, the largest model considered was a 12-variable model which included all explanatory variables with regression values so that: $-1.0 \geq t \geq +1.0$.[1/] The smallest model considered was a 5-variable model with values for all inclusive variables: $-2.0 \geq t \geq +2.0$. In all models considered, each discriminant function produced means of the good groups and poor groups that were significantly different at the $\alpha = 0.025$ level. Models with 8 or fewer variables produced significantly different means at the $\alpha = 0.01$ level (largest characteristic root test, Morrison 1967).

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1/ Note: For the t test for sample sizes of n = 20, anything at or near 2.0 is significant at $\alpha = 0.05$. With n = 78, the t = 2.00 is significant at $\alpha = 0.03$, whereas the $\alpha = 0.05$ has a t value = 1.67 and the $\alpha = 0.10$ one = 1.29 (Brownlee 1960).

Stage 4 was the most thorough and rewarding stage. Three key models were identified immediately for detailed comparative analysis. They were: 5-, 8-, and 12-variable models with the general characteristics shown in table 2.

Any process providing for final model selection is necessarily arbitrary and subjective. Because the explanatory variables had inclusive t-values near the $\alpha = 0.05$ level and the function discriminated between good and poor means at the $\alpha = 0.01$ level, the eight-variable model was chosen for reporting analysis. The extra costs of collecting data and manipulating a larger equation were also considered part of the trade-off in model selection. We accepted a middle ground between data costs and statistical accuracy.

The selected 8-variable discriminant function is:

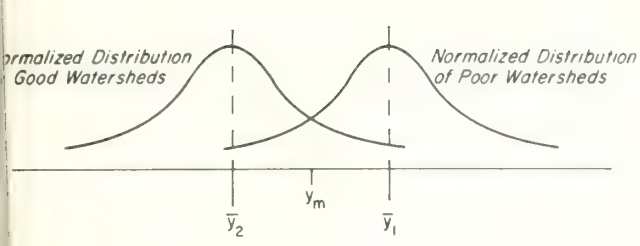
$$f(x) = -0.002787\ X_1 - 0.602159\ X_3 - 0.019247\ X_4 - 0.029875\ X_6 + 0.002146\ X_7 + 0.000332\ X_{12} - 0.023515\ X_{18} + 0.000660\ X_{19}.$$

For discussion purposes, let $f_1(x) = y_1$ express functional output for the poor group and $f_2(x) = y_2$ for the good group. Figure 3 underscores the generalized multivariate normality (multinormal) concept assumed related to this application of the discriminant analysis; it illustrates a tailored version of the discrimination provided by this model between the good groups and poor groups.

Table 2--*Discriminant model characteristics*

| Model | Explanatory variables | Significant delineating characteristics (s) |
|---|---|---|
| 5-variable[1/] | $X_1$, $X_3$, $X_4$, $X_{12}$, $X_{19}$ | Means significant @ $\alpha = 0.01$<br>All inclusive t-values:<br>$-2.0 \geq t \geq +2.0$ |
| 8-variable | $X_1$, $X_3$, $X_4$, $X_6$, $X_7$, $X_{12}$, $X_{18}$, $X_{19}$ | Means significant @ $\alpha = 0.01$<br>All inclusive t-values:<br>$-1.5 \geq t \geq +2.0$ |
| 12-variable | $X_1$, $X_2$, $X_3$, $X_4$, $X_6$, $X_7$, $X_{11}$, $X_{12}$, $X_{14}$, $X_{16}$, $X_{18}$, $X_{19}$ | Means significant @ $\alpha = 0.025$<br>All inclusive t-values:<br>$-1.0 \geq t \geq +1.0$ |

[1/] Smaller models were not considered due to very high degree of significance of removing variables beyond the five listed.




$\bar{y}_1 = 0.152$

$y_m = (\bar{y}_1 - \bar{y}_2) / 2 = 0.070$

$\bar{y}_2 = -0.012$

$\sigma_1^2 = \sigma_2^2 = 0.013$

$\bar{y}_1$ significantly different from $\bar{y}_2$ @ the $\alpha = 0.01$ level

*Figure 3.--Normalized distributions of good and poor watersheds for eight-variable discriminant model.*

## Application

The next step was development, application, and evaluation of classification rules. All classification rules depend directly on any "a priori" probability information on occurrence of both groups $y_1$ and $y_2$. One approach is to assume no such knowledge exists, hence probability ($P_1$) of $y_1$ is equal to probability ($P_2$) of $y_2$. And, because $P_1 + P_2 = 1.0$, both $P_1$ and $P_2$ are equal to 0.50. A second approach is to assume the available relative frequencies approximate the $P_1$ levels. Hence: $P_1 = 22/78 \simeq 0.30$ and $P_2 = 56/78 \simeq 0.70$. The problem with the second approach is that it assumes that the sampling techniques were truly random. When sampling is not random, relative frequencies are not used to approximate the $P_1$ "a priori" probabilities (Morrison 1967, Cooley and Lohnes 1971). For this problem, because of the state of the existing data base (highly local and ease of access oriented) and the constraints of accepting only truly poor or truly good producing streams, the technique was not random. This in no way affects any of the analytical procedures for discriminant functions (Morrison 1967); however, it precludes the use of relative frequencies as "a priori" probabilities. For classification analysis, $P_1 = P_2 = 0.50$ was the "a priori" estimate used. If and when future research indicates different levels of $P_1$ and $P_2$, such modifications can be entered in the analysis. The appendix illustrates just how $P_1$ and $P_2$ enter into the calculation of the posterior probabilities that dictate classification.

In general, where $P(y_1)$ and $P(y_2)$ represent posterior probabilities of $y_1$ and $y_2$, a classification rule is:

When $L_{1,2}P(y_2) \geq L_{2,1}P(y_1)$, classify as $y_2$; otherwise as $y_1$. Here, $L_{2,1}$ represents the expected loss for misclassifying a poor ($y_1$) as a good ($y_2$), and $L_{1,2}$ the expected loss for misclassifying a good ($y_2$) as a poor ($y_1$). The equal sign is relevant and can classify the function value as either a good producer or a poor producer. When $L_{1,2} = L_{2,1}$, this reduces to: Classify as $y_2$ when $P(y_2) \geq P(y_1)$; otherwise as $y_1$. For analysis purposes, we assumed $L_{1,2} = L_{2,1}$, and when $P_1 = P_2$ then $L_{1,2}P_1 = L_{2,1}P_2$. This simplifies the decision rule (Morrison 1967): When $f(x) \geq y_m$, classify as $y_1$; otherwise as $y_2$. Refer to figure 4 for this rule (Rule I). Application of Rule I to the 78 watersheds in the study yielded the results shown in table 3.

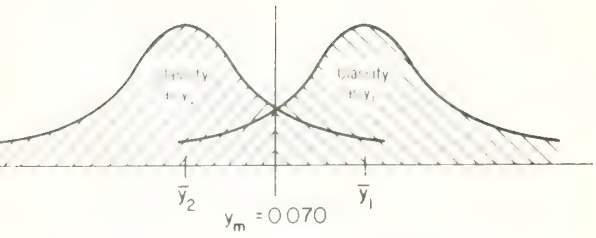



*Figure 4.--Classification Rule I.*

A modification to Rule I provides for selecting a band bracketing either side of $y_m$ so that any f(x) values falling within the band are not classified. Figure 5 illustrates this concept.

Application of Rule II to the 78 watersheds, where the lower limit ($E_\ell$) is 0.05, the upper limit ($E_u$) is 0.09, and $y_m$ is 0.07, yielded the results

Table 3--*Classification of 78 watershed by Rule I*

| Classified by discriminant function and Rule I | Preanalysis classification | | |
|---|---|---|---|
| | Good | Poor | Total |
| | Number of watersheds | | |
| Good | 41 | 5 | 46 |
| Poor | 15 | 17 | 32 |
| Total | 56 | 22 | 78 |

Here, 20 out of 78 watersheds were misclassified, abou 26 percent. If $L_{2,1}$, $L_{1,2}$, $P_1$ and $P_2$ are different from assumed levels, this would be altered by applying the techniques shown in the appendix. Under assumptions used here, application of the selected discriminant function yields much better results than assumptions of 50-50 possibilities (e.g., "a priori" probability = 0.50).

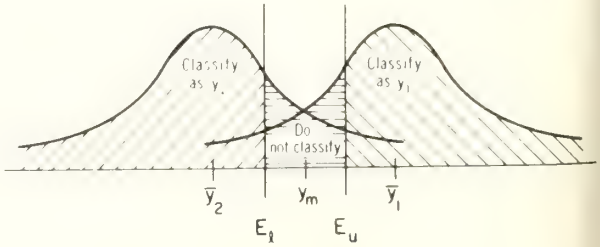



*Figure 5.--Classification Rule II.*

shown in table 4; where 13 watersheds out of 78 are misclassified (about 17 percent). Also, 13 watersheds out of 78 are not classified; so of the 65 classified, Rule II misclassifies 13 watersheds or 20 percent.

Actually, Rule I misclassifies 5 out of 22 poor (23 percent); Rule II, 2 out of 18 (11 percent). Rule I misclassifies 15 out of 56 good (27 percent); Rule II, 11 out of 47 (23 percent). Rule II is better than Rule I if we assume that the decisionmaker does not wish to classify the f(x) values clustered closely about $y_m$. Tables 5 and 6 illustrate the percentages of

Table 4--*Classification of 78 watersheds by Rule II*

| Classified by discriminant function and Rule II | Preanalysis classification | | |
|---|---|---|---|
| | Good | Poor | Total |
| | Number of watersheds | | |
| Good | 36 | 2 | 38 |
| Neutral | 9 | 4 | 13 |
| Poor | 11 | 16 | 27 |
| Total | 56 | 22 | 78 |

Table 5--*Generalized application of Rule I by percentages*

| Classification by normalized curves | Posterior percentage of total group | |
|---|---|---|
| | Good | Poor |
| Good | 77 | 23 |
| Poor | 23 | 77 |
| Total | 100 | 100 |

Table 6--*Generalized application of Rule II by percentages*

| Classification by normalized curves | Posterior percentage of total group | |
|---|---|---|
| | Good | Poor |
| Good | 71 | 18 |
| Neutral | 11 | 11 |
| Poor | 18 | 71 |
| Total | 100 | 100 |

the normalized curves for Rules I and II that generally fall into the categories specified.

## Discussion

The results of the data analysis provide us with a linear equation yielding at least a qualitative estimate of productivity of pink and chum salmon for southeast Alaska watersheds. The method is simple, flexible, much more accurate than assuming 50-50 probabilities, and responsive to the demands of the decision-maker. The land manager is provided with an analytical tool that can be used in solving land use problems. For example, a decisionmaker faced with a problem of allocating funds for protection or improvement of pink and chum salmon streams could use the discriminant function to classify very poor watersheds and very good watersheds. Then, based on managerial priorities for protection or enhancement of pink and chum salmon habitat commensurate with other resource values, he could determine appropriate allocation of funds.

Additional areas of managerial application involve land use decisions which may have an impact on salmon production. A land manager would benefit from knowing which watersheds are good producers of pink and chum salmon and which are poor producers. He could then take steps to minimize impact in watersheds with high production.

For the scientist and researcher, this tool provides a direct means of choosing an exceptionally good or an exceptionally poor salmon-producing watershed for more refined analysis of factors affecting productivity. It can direct the researcher to watersheds that have a higher probability of defining variables most likely to influence the level of pink and chum salmon production.

The important point is that, in general, the discriminant function developed from this research is a flexible tool that has potential dual utility: in land management decisions, a classification into poor or good categories aids the decisionmaking process; in research applications, it assists in detailed variable cause and effect analysis.

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# Appendix

*Posterior Probabilities and Classification Comments*

A. Posterior probabilities:

Two basic equations are solved simultaneously to obtain posterior probabilities:

1. $P(y_1) + P(y_2) = 1.0$.

2. $P(y_i) = C_b P_i f_i(y)$; $i = 1,2$.

Where: y is the value of the discriminant function for a watershed;

$P(y_1)$ is the posterior probability of the value y being classified in the poor group.

$P(y_2)$ is the posterior probability of the value y being classified in the good group.

$P_i$ is the "a priori" probability for the respective poor ($P_1$) and good ($P_2$) groups.

$C_b$ is a constant to be determined.

$f_i(y)$ is the value of the function on y:

$$f_i(y) = \frac{1}{\sqrt{2\pi}\ \sigma_i}\left[e^{-(1/2\sigma^2)(y-\bar{y}_i)^2}\right].$$

$\pi$ is the value 3.1416.

$\sigma_i$ is the standard deviation of group i discriminant values.

$\bar{y}_i$ is the mean of group i discriminant values.

e is natural log base e; value of 2.7183.

For this study two simplifications were made:

1. For the 8-variable model discriminant function,

a. $\sigma_1^2 = s_1^2$ and $\sigma_2^2 = s_2^2$.

s represents significant delineating characteristics (see table 2).

b. $s_1^2 = 0.0112$ and $s_2^2 = 0.0139$.

c. Assume $\sigma_1^2 = \sigma_2^2 = \sigma^2$ and use:

$$s^2 = [(n-1)s_1^2 + (m-1)s_2^2]/(m + n-2).$$

m and n represent respective sample sizes for groups 1 and 2.

d. $s^2 = 0.013$; where $s^2 \doteq \sigma^2$.

e. Hence, $\sigma_1^2 = \sigma_2^2 = s^2$ (Wetherill 1967).

2. The "a priori" probabilities are assumed equal:

$$P_1 = P_2 = 0.50.$$

This allows reduction of the $f_i(y)$ function to only its variable portion:

$$f_i(y) = e^{-(1/2\sigma^2)\ (y-\bar{y}_i)^2}.$$

Here, $\frac{1}{\sqrt{2\pi}\ \sigma_i}$ will always be constant; therefore, it is included as part of the to-be determined constant:

$C = \frac{1}{\sqrt{2\pi}\ \sigma_i} C_b$, and $C = 1/[\Sigma f_i(y)]$.

The posterior probabilities can be calculated now using this information. For:

$\bar{y}_1 = 0.1520$ (mean poor group).

$\bar{y}_2 = -0.0120$ (mean good group).

$\sigma^2 = s^2 = 0.0130$.

B. Classification comments:

Classification into good and poor groups cannot rely alone on values of the discriminant function and respective posterior probabilities. The basic guideline is: $L_{2,1}\ P(y_1) \leq L_{1,2}\ P(y_2)$. Here $L_{2,1}$ is the cost of misclassifying a poor group as good; and $L_{1,2}$, the cost of misclassifying a good group as poor. When this inequality holds, classify the value for y as a member of the good group; otherwise as a member of the poor group. For $L_{2,1} = L_{1,2}$ the analyst can use just the posterior probabilities: $P(y_1) \leq P(y_2)$ implies classification as good, otherwise as poor.

| y | $(y-\bar{y}_1)$ | $(y-\bar{y}_1)^2$ | $(y-\bar{y}_2)$ | $(y-\bar{y}_2)^2$ | $\sigma^2$ | $\frac{1}{2\sigma^2}$ | $f_1(y)$ | $f_2(y)$ | $\Sigma f_i(y)$ | C | $\frac{1}{\Sigma f_i(y)}$ | $P(y_1)$ | $P(y_2)$ | $\Sigma P(y_i)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.040 | −0.112 | 0.0125 | 0.052 | 0.0027 | 0.013 | −38.46 | 0.6183 | 0.9014 | 1.520 | 0.658 | 0.658 | 0.4068 | 0.5932 | 1.0 |
| 0.050 | −0.102 | 0.0104 | 0.062 | 0.0038 | 0.013 | −38.46 | 0.6703 | 0.8640 | 1.534 | 0.649 | 0.649 | 0.4350 | 0.5650 | 1.0 |
| 0.060 | −0.092 | 0.0085 | 0.072 | 0.0052 | 0.013 | −38.46 | 0.7211 | 0.8187 | 1.540 | 0.650 | 0.650 | 0.4687 | 0.5313 | 1.0 |
| 0.070 | −0.082 | 0.0067 | 0.082 | 0.0067 | 0.013 | −38.46 | 0.7728 | 0.7728 | 1.550 | 0.645 | 0.645 | 0.5000 | 0.5000 | 1.0 |
| 0.080 | −0.072 | 0.0052 | 0.092 | 0.0085 | 0.013 | −38.46 | 0.8187 | 0.7211 | 1.540 | 0.650 | 0.650 | 0.5322 | 0.4678 | 1.0 |
| 0.090 | −0.062 | 0.0038 | 0.102 | 0.0104 | 0.013 | −38.46 | 0.8640 | 0.6703 | 1.534 | 0.649 | 0.649 | 0.5607 | 0.4393 | 1.0 |
| 0.100 | 0.052 | 0.0027 | 0.112 | 0.0125 | 0.013 | 38.46 | 0.9014 | 0.6183 | 1.520 | 0.658 | 0.658 | 0.5932 | 0.4068 | 1.0 |

For: $f(x) = -0.002787x_1 - 0.602159x_3 - 0.019247x_4 - 0.029875x_6 + 0.002146x_7 + 0.000332x_{12} - 0.023515x_{18} + 0.000660x_{19}$. $(f(x) = y)$.

When the "a priori" probabilities can be determined to be something other than equal (e.g., $P_1 = P_2 = 0.50$), the calculation of posterior probabilities is still straightforward. The analyst simply uses a value other than 0.50 in $P(y_i) = CP_i f_i(x)$ for the $P_i$ term. The theory and analysis remain unaltered.

The important point here is that the decisionmaker or researcher (user of analysis results) must determine his costs of wrong classification before the method can be applied. Exact costs need not be determined. Simple cost ratios (R) will suffice: $L_{2,1}/L_{1,2} = R_{2,1}/R_{1,2}$. Then use $R_{2,1}P(y_1) \leq R_{1,2}P(y_2)$ as the guideline.



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Swanston, Douglas N., William R. Meehan, and James A. McNutt. 1977. A quantitative geomorphic approach to predicting productivity of pink and chum salmon streams in southeast Alaska. USDA For. Serv. Res. Pap. PNW-227, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Twenty one quantitative geomorphic variables, measured from aerial photographs and topographic and geologic maps of 78 watersheds, were tested for significance in differentiating between good and poor producers of pink and chum salmon. A discriminant model was then constructed. Using this model, the decisionmaker can make a qualitative estimate of potential pink and chum salmon production for any southeast Alaska watershed with minimum field investigation.

KEYWORDS: Fish management, geomorphology, salmonids, Alaska (southeast).

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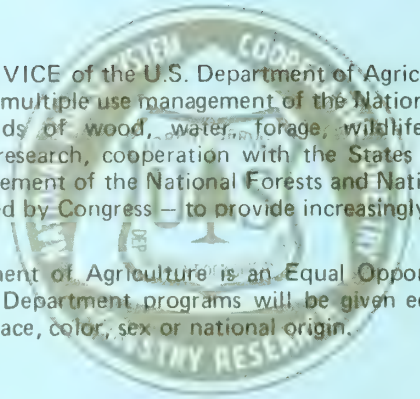

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# Effects of AERIAL APPLICATION OF DDT on Reproduction in House Wrens and Mountain and Western Bluebirds

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E. Charles Meslow

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

# Contents

# *Effects of Aerial Application of DDT on Reproduction in House Wrens and Mountain and Western Bluebirds*

*Reference Abstract*

McCluskey, D. Calvin, Jack Ward Thomas, and E. Charles Meslow. 1977. Effects of aerial application of DDT on reproduction in house wrens and mountain and western bluebirds. USDA For. Serv. Res. Pap. PNW-228, 22 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

No significant adverse effect on reproductive success of mountain bluebirds (*Sialia currucoides*), western bluebirds (*S. mexicana*), and house wrens (*Troglodytes aedon*) was detected after aerial application of DDT at a rate of 0.84 kilogram per hectare. The 2-year study determined the fate of 656 eggs within the spray area and 711 eggs within the control area.

KEYWORDS: Pesticide side effects, birds, mountain bluebirds, western bluebirds, house wrens, DDT, spraying (aerial).

*RESEARCH SUMMARY*

*Research Paper PNW-228*

*1977*

Observations of mountain bluebirds *(Sialia currucoides)*, western bluebirds *(S. mexicana)*, and house wrens *(Troglodytes aedon)* nesting in northeast Oregon were recorded for two breeding seasons after aerial applications of DDT at a rate of 0.84 kilogram per hectare (0.75 pound per acre). Numbers of eggs laid, eggs hatched, and young fledged from sprayed and control areas in 1974 and 1975 were compared. In 1975 additional data on weight gains and rate of nestling development were collected for mountain and western bluebirds. Population indices were made for flying insects in 1974 and 1975 and for ground dwelling insects in 1975 for sprayed and control areas. All statistical tests were examined for differences at the $P=\leq 0.05$ level.

No significant differences between sprayed and control areas for clutch size, hatching success, or fledging success were observed for mountain bluebirds in 1974. There was a significant difference in clutch size for house wrens in 1974, but the difference was not attributed to DDT since spray application took place after eggs were laid. There was no significant differences in success in hatching or fledging between sprayed and control areas for house wrens in 1974.

Because of the small sample of western bluebird nests for sprayed areas, no statistical comparisions were made in 1974.

In 1975 there were no significant differences between clutch size for all three species in sprayed and control areas. There was no significant difference in success in hatching or fledging between sprayed and control areas for mountain bluebirds in 1975. There were differences for western bluebirds and house wrens.

No significant differences in mortality rates of nestlings were detected in either 1974 or 1975; only deaths that might have been caused by DDT were considered.

Comparisons of the three measures of reproduction between years for mountain bluebirds revealed significantly lower success in hatching and fledging in 1975. The difference was not attributed to DDT since success in hatching was greater in sprayed areas.

There were no observed differences in rates of nestling development or nestling weight gains for mountain or western bluebirds between sprayed and control areas. Unseasonal weather conditions and increased predation were believed to be the causes for lower success in hatching and fledging in 1975.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife -- if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

## Introduction

This report is on an investigation of the effects of aerial applications of 0.84 kilogram per hectare (0.75 lb per acre) of technical grade DDT (dichlorodiphenyltrichloro-ethane) on success in reproduction of mountain bluebirds *(Sialia currucoides)*, western bluebirds *(S. mexicana)*, and house wrens *(Troglodytes aedon)*.

Extensive use of DDT after World War II resulted in widespread contamination of the biosphere (Dustman and Stickel 1966). Residues of DDT were recorded in thousands of species and in remote areas such as Antarctica (Tatton and Ruzicka 1967). DDT is a persistant chlorinated hydrocarbon that lasts an average of 4 years in the environment when it is applied at a rate of 0.56-0.84 kg/ha (0.5-0.75 lb/acre); applications of 1.8-2.3 kg/ha (4.0-5.0 lb/acre) may persist for 8-12 years (Kearney et al. 1969). In addition to its persistence, DDT or its metabolites are fat soluble, allowing them to accumulate and concentrate in fatty tissues of organisms (Macek 1970).

The immediate and most obvious effect of DDT on success in reproduction of avian populations is death of nestlings (Hotchkiss and Pough 1946, Adams et al. 1949, Mitchell et al. 1953, Wurster et al. 1965). Less obvious effects include reduced clutch size (Rubin et al. 1947), reduced success in hatching (Hickey and Anderson 1968, Heath et al. 1969), and reduced success in fledging (Ratcliffe 1965). Sex (Wurster 1969) and physical condition (Gish and Chura 1970, Stickel et al. 1965, Wurster 1969) were shown to be important variables influencing susceptibility to the toxic effects of DDT.

This research was initiated to explore the effects of aerial applications of DDT on bluebirds and house wren populations living in grasslands adjacent to forests treated for an outbreak of Douglas-fir tussock moth (*Orygia pseudotsugata* (McDunnough)). Measures of success in reproduction monitored during this study were clutch size, hatching success, and fledging success.

In addition, we examined certain insect populations to determine if any declines in insect biomass had occurred. Data on weight gains and development of nestlings were collected in 1975 as additional monitoring devices of available food supplies. Because little is known about insect food requirements of nestling bluebirds and house wrens, we felt that weight gain and development measurements might reflect a possible decline of certain important insect species that otherwise would not be detected.

Mountain bluebirds, western bluebirds, and house wrens were selected for study because they:

(a) are common summer residents of the grasslands included within the study areas (Gabrielson and Jewett 1940);

(b) are predominantly insectivorous during summer months (Martin et al. 1951; Beal 1915; Bent 1948, 1949; Knowlton and Harmston 1946);

(c) readily accept nest boxes (Headstrom 1970, Gabrielson and Jewett 1940);

(d) nest at 1-2 meters, (3.9-6.6 ft), allowing observations of nests and handling of their contents with minimum effort (Headstrom 1970, Powers 1966).

## Study Areas

Two study areas were selected for placement of nest boxes (fig. 1): the La Grande unit, centered 15 km (9.3 mi) northeast of the city of La Grande, Union County, Oregon, and the Wallowa unit, centered approximately 20 km (12.4 mi) north of the city of Wallowa, Wallowa County, Oregon. Boxes in sprayed and control areas were located within the boundaries of the two units (fig. 1 and the appendix).

Areas for placement of nest boxes were selected from topographic maps and aerial photographs of the areas proposed for treatment. Criteria used in selection of study areas were:

1. Each area provided comparable amounts of nesting habitat for bluebirds and house wrens.

2. The areas had to be accessible by truck at least 6 months of the year.

3. Each area had to contain comparable numbers of the three study species.

These two areas were considered the population or populations. Any extension of results outside the condition of these areas would constitute extrapolation of the data. From

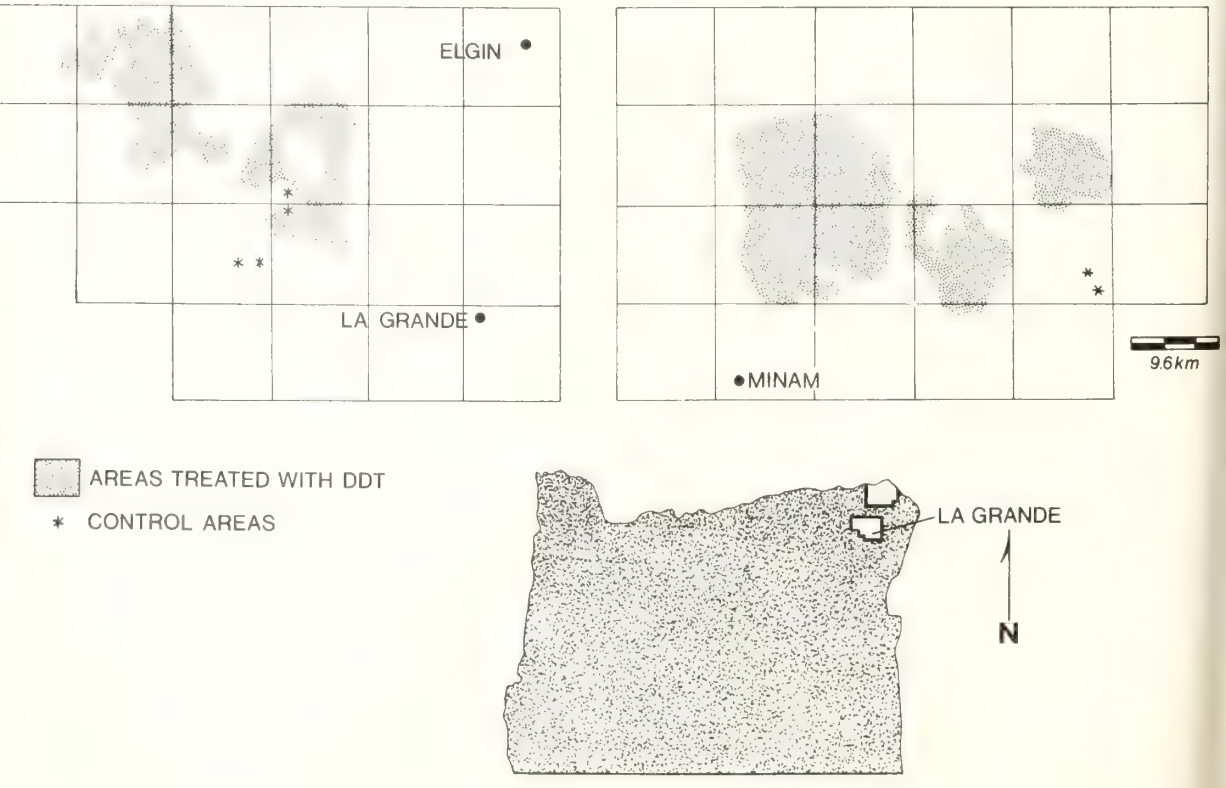


*Figure 1.--Location of La Grande (left) and Wallowa (right) study areas in northeast Oregon, 1974-75.*

pooled data sampled from each area, we assumed that the range in variation of these two areas was representative of the conditions to which we wished to draw inference. We further assumed that the samples of both treated and control areas were random, independent samples of these conditions.

## Materials and Methods

A modification of bluebird nest boxes described by Schutz (1974) was used in the construction of 550 nest boxes.

In the spring of 1974, 250 nest boxes were placed in areas proposed for treatment; 300 boxes were placed as controls in proposed untreated areas. Changes in boundaries of the proposed spray areas before treatment, combined with low occupancy rates during the 1974 breeding season, led to relocation of 150 of 239 unused boxes from areas not sprayed to sprayed areas for the 1975 breeding season.

### REPRODUCTION

Nest boxes were examined during the 1974 breeding season at 2- to 21-day intervals, In 1975, more personnel were available and nest boxes were examined at 2- to 6-day intervals. Boxes were opened on each visit and their contents examined.

Clutch size was defined as the number of eggs present at the onset of incubation. Differences between spray and nonspray areas were tested by means of a $t$-test (Snedecor and Cochran 1967).

We compared clutch size with the number of eggs hatched (proportion of eggs laid that hatched) to determine hatching success, and the number of young fledged with the number of young hatched (proportion of young hatched that fledged) to determine fledging success. Differences between spray and nonspray areas were examined by use of chi-square tests for independence (Snedecor and Cochran 1967). Because intervals between observations were 2-21 days in 1974 and 2-6 days in 1975, fledging numbers in many cases were derived circumstantially. Criteria used to determine fledging numbers were similar to those used by Powers (1966) in Montana: (a) age and condition of young at the previous examination; (b) a well-matted nest with an abundance of fecal material, indicating fledgling-age nestlings had been in the nest box; (c) absence of evidence of nest disturbance and/or predation.

### WEIGHT GAINS

Data on nestling weight gains from the time of hatching to fledging were recorded so we could compare growth rates of nestlings living in sprayed and control areas in 1975. Nestlings from 8 mountain bluebird nests and 10 western bluebird nests from control areas and 20 mountain bluebird nests and 25 western bluebird nests from sprayed areas were weighed at 1-3 day intervals and compared by use of an $F$-test (Snedecor and Cochran 1967, p.125).

### NESTLING DEVELOPMENT

To determine the effect on time of development of nestlings caused by the reduced insect food base, we compared the mean number of days to fledging for nestlings from 15 mountain bluebird nests and 10 western bluebird nests in control areas and 31 mountain bluebird nests and 24 western bluebird nests from sprayed areas. The $t$-test (Snedecor and Cochran 1967) was used to make these tests. No comparisons were made for house wrens because the small sample was further reduced by predators.

## INSECT NUMBERS

To determine if there was a significant decline in density of insects, the dominant food item of bluebirds and house wrens, Butler (1965) obtained an index to numbers of flying insects in 1974 and 1975 from 13 malaise net traps. Seven traps were located in sprayed areas and six in control areas. Contents were collected at 3- to 8-day intervals. The air-dry weight of each sample was recorded and was used to calculate the rate of capture (weight per day) of insect biomass. The rate of decline in insect capture rates after DDT application in the spring was tested for significance by use of the F-test (Snedecor and Cochran 1967).

Numbers of grasshoppers were indexed during 1975 in the following manner. Ten 100-m (328-ft) transects were established in similar habitats in sprayed and control areas. Three 100-m (328-ft)-long sweeps with a 46.2-cm (18-in) diameter sweep net were made along each transect and the number of grasshoppers captured was recorded. Rates of capture between spray and nonspray areas were tested by use of the t-test (Snedecor and Cochran 1967).

## NESTLING MORTALITY

Nestling mortality was recorded during each nest box check. If nestlings were missing before they reached fledging age, they were considered fatalities. The cause of death in each case was placed in one of two categories, "predation" or "other causes." Criteria used in determining deaths caused by predators were: (a) absence of prefledgling-age nestlings, (b) obvious signs of nest disturbance or destruction accompanied by dead or missing nestlings, and (c) remains of nestlings.

Nestling losses that did not fit the above criteria were placed in the category "other causes".

## DDT APPLICATION

DDT reaching ground level was measured on three 10.2- by 12.7-cm (4- by 5-in) oil sensitive cards (White 1959) placed near each nest box. Because all three study species commonly nest at the forest edge adjacent to grasslands, we made simultaneous measurements of DDT applications at three different points for each nest box. One card was placed at the box, one card 20 m (65.6 ft) from the box in the adjacent clearing, and one card 20 m (65.6 ft) into the wooded area. Each card was stapled to a wooden stake and placed at ground level. The spray cards were placed in the field 12-24 hours before DDT was applied.

The spray cards were analyzed by a visual comparison of the number and size of spray droplets on each sample card with the standards for estimating airplane spray deposits on oil sensitive cards described by Maksymiuk (1963) and Davis and Elliot (1953). The mean value of the three cards was considered the DDT level at that box.

Because of personnel shortages and logistics, the control areas were not monitored for DDT drift. Information gathered by other Forest Service personnel engaged in monitoring the spray application indicated that negligible spray drift was recorded 61 m (200 ft) from the spray boundaries and no spray was recorded 122 m (400 ft) from the spray boundaries. Control areas were therefore assumed to be uncontaminated by spray. This assumption was supported experimentally by T. Torgersen (personal communication), a

research entomologist with the Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, who placed caged adult sarcophagid flies *(Agria housei)* in treated and untreated areas before the DDT applications. All of Torgersen's flies in treated areas died, but none of those in control areas, 400-800 m (1,312.3-2,624.6 ft) from the treated areas, died. It should be noted, however, that the study areas used had exposure to DDT prior to the 1974 applications. Between 1950 and 1955, the Forest Service sprayed DDT at a rate of 1.2 kg/ha (1.0 lb/acre) on six areas in northeast Oregon. These applications led eventually to total coverage of both control and treated areas. Because DDT persists for an average of 4 years in the environment when applied at 1.2 kg/ha (1.0 lb/acre), there was little chance that DDT residues from the 1950-55 spray projects would still be available for ingestion by bluebirds or house wrens (Kearney et al. 1969).

### STATISTICAL TESTS—LEVELS OF SIGNIFICANCE

All statistical tests were evaluated with $P \leq 0.05$ as the criterion for acceptance or rejection of hypotheses.

## Results

### DDT LEVELS IN SPRAYED AREAS

The average amount of DDT recorded at ground level was 0.081 kg/ha (0.072 lb/acre) at the nest box, 0.075 kg/ha (0.067 lb/acre) in the forest, and 0.175 kg/ha (0.156 lb/acre) in the open (table 1). Data from 419 additional cards, from U.S. Forest Service monitoring teams, placed in a stratified manner across treated areas revealed an average of 0.202 kg/ha (0.18 lb/acre) at ground level.

The reasons for the large difference between the applied

Table 1--*DDT reaching ground level at four locations around nest boxes in sprayed areas, northeast Oregon, 1974*[1/]

| Location[2/] | Forest[3/] | Nest Box | Open[4/] |
|---|---|---|---|
| | Kilogram per hectare | | |
| Powatka | 0.126 | 0.088 | 0.153 |
| McAllister | .062 | .072 | .233 |
| Horseshoe | .064 | .071 | .081 |
| McAllister II | .051 | .095 | .273 |
| Combined average | .075 | .081 | .175 |
| Variance | .001 | .001 | .002 |

[1/] Application rate was 0.84 kilogram per hectare.

[2/] Location names refer to ridges where nest boxes were located.

[3/] 20 meters (66 feet) from nest box into forested area.

[4/] 20 meters (66 feet) from nest box into adjacent clearing.

rate and the rate measured on the ground were:

1. The surrounding vegetation (trees and shrubs) caused a screening effect (Maksymiuk 1963b).

2. DDT spray volatized before it reached ground level (Maksymiuk 1963b).

3. The helicopter pilots were instructed to shut off the spray when crossing grasslands larger than 0.81 ha (2 acres). Shut off and release of spray occurred at or very near actual box locations, which resulted in variable amounts of DDT reaching the ground around each box (Thomas and McCluskey 1974).

For additional details on sample sizes and standard deviations by spray area, see Thomas and McCluskey (1974).

## INSECT RESPONSE TO DDT APPLICATIONS

The malaise traps captured only flying insects, which reportedly comprise a large portion of bluebirds' diet (Criddle 1927; Powers 1966, p. 361) but only a minor portion of the insect food for house wrens (Knowlton and Harmston 1946, Bent 1948). Although these traps have limitations when used for studying food supplies of bluebirds and house wrens, they were the most effective tool available when expense, time, and availability of personnel were considered.

Rates of capture for insects were measured in milligrams of biomass trapped per day. In 1974 the rate of capture generally declined on both sprayed and control areas prior to DDT applications (June 23-24)(fig. 2).

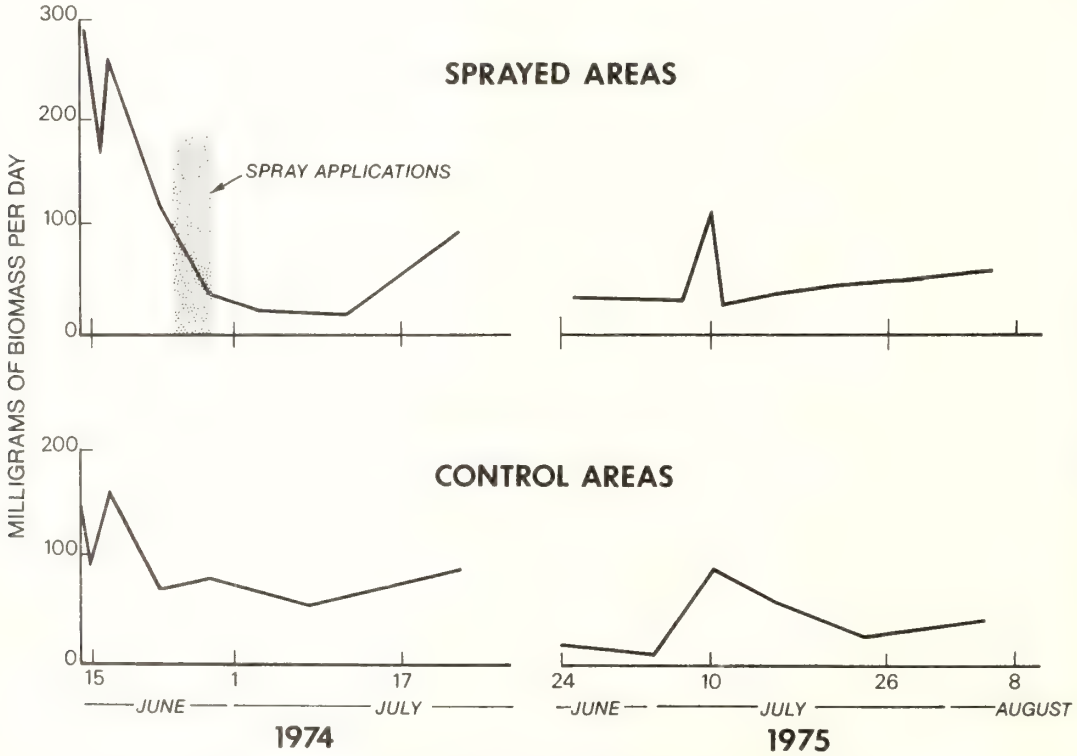


*Figure 2.--Average rate of capture for flying insects in sprayed and control areas in northeast Oregon, 1974-75.*

Insect capture rates, however, decreased significantly (d.f.=13, $F$=16.16) on treated areas immediately after DDT applications. Insect capture rates on sprayed areas declined by 80.7 percent compared with 41.9 percent on untreated areas.

Insect capture rates in 1975 were similar for both sprayed and control areas with no significant differences (d.f.=11, $F$=0.466) detected (fig. 2).

Grasshoppers collected in August 1975 served as an index to the abundance of ground dwelling insects. The mean number of grasshopper captures per transect was 5.1 (range 2-9) in sprayed areas and 4.9 (range 1-9) in control areas. A $t$-test indicated no significant differences (d.f.=18, $t$=0.190) in mean numbers captured between sprayed and control areas.

## CLUTCH SIZE

Applications of DDT took place in 1974 after most egg clutches were laid; therefore, these applications of DDT could not affect clutch size. Likewise, DDT could affect hatching success in 1974 only if it altered adult behavior, caused adult mortality, or penetrated the eggshell (from pesticide materials on feathers of adults).

In 1974, a $t$-test indicated no significant difference (d.f.=57, $t$=0.584) in clutch sizes between sprayed and control areas for mountain bluebirds. There was a significant difference (d.f.=12, $t$=2.401) in mean clutch sizes for house wrens. Because there was only one western bluebird nest in sprayed areas, no statistical comparisons were made for this species.

During 1975, results were similar; for mean clutch sizes for the three species studied, there was no significant difference (d.f.=85, $t$=0.680 mountain bluebirds; d.f.=81, $t$=0.220 for western bluebirds; d.f.=5, $t$=0.398 for house wrens).

Data are displayed in table 2.

## HATCHING SUCCESS

In 1974, hatching success was similar on sprayed and control areas. A chi-square test for independence (Snedecor and Cochran 1967, p. 125) revealed no significant differences (d.f.=1, $X^2$=0.65) in hatching success between sprayed and control areas for mountain bluebirds or house wrens.

A chi-square comparison of hatching success in 1975 between sprayed and control areas revealed no significant differences (d.f.=1, $X^2$=3.27) for mountain bluebirds. Comparisons between sprayed and control areas of hatching success for western bluebirds and house wrens did result in significant differences (d.f.=1, $X^2$=10.54 for western bluebirds; d.f.=1, $X^2$=4.36 for house wrens). Western bluebirds hatched an average of 4.3 eggs in sprayed areas and 3.6 in control areas. House wrens nesting in sprayed areas had an average hatch of 6.0, and birds in control areas hatched 4.0 eggs per clutch (table 2).

All eggs were treated as random, independent observations; that is, the degrees of freedom were computed on the basis of numbers of eggs, not on numbers of nests.

Table 2--*Clutch size, hatching, and fledging success for mountain bluebirds, western bluebirds, and house wrens nesting in both treated and untreated study areas in northeast Oregon, 1974-75*

| Species | 1974 | | | | | | 1975 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N (eggs) | Average clutch (number of eggs) | Average hatch (number of eggs) | Percent hatch | Average number fledged | Percent fledged | N (eggs) | Average clutch (number of eggs) | Average hatch (number of eggs) | Percent hatch | Average number fledged | Percent fledged |
| ountain luebird sprayed) | 63 | 5.3 (.16) | 5.1 | 96.8 | 5.1 | 100 | 267 | 5.0 (.10) | 4.2 | 83.1 | 3.2 | 75.2 |
| ountain luebird ontrol) | 246 | 5.2 (.10) | 4.9 | 93.1 | 4.9 | 100 | 167 | 4.9 (.16) | 3.7 | 76.0 | 2.6 | 69.3 |
| estern luebird sprayed) | 6 [2] | 6.0 | 5.0 | 83.3 | 5.0 | 100 | 227 | 5.3 (.15) | 4.3* | 81.5 | 2.8* | 65.9 |
| estern luebird ontrol) | 44 | 4.9 | 4.9 | 100 | 4.9 | 100 | 213 | 5.3 (.15) | 3.6* | 68.1 | 2.1* | 56.5 |
| ouse wren sprayed) | 60 | 6.7* (.34) | 5.9 | 88.3 | 5.9 | 100 | 33 | 6.6 (.51) | 6.0* | 90.9 | 4.0* | 66.6 |
| ouse wren ontrol) | 27 | 5.4* (.50) | 4.4 | 81.5 | 4.0 | 72.7 | 14 | 7.0 (1.0) | 4.0* | 57.1 | 1.5* | 37.5 |

*Indicates significant differences ($P \leq 0.05$) between sprayed and control areas.

[1] Standard errors are in parentheses.

[2] Clutch sizes were not compared.

## FLEDGING SUCCESS

Because DDT was applied on the study areas on June 23-25, 1974, the pesticide could have affected only survival of nestlings.

Fledging success for mountain and western bluebirds living on both sprayed and control areas in 1974 was 100 percent (table 2). House wrens nesting in sprayed areas averaged 5.9 young fledged per nest or 100 percent and those nesting in control areas averaged 4.0 young per nest for a success rate of 72.7 percent. The DDT applied had no deleterious effect on fledging success for the three species in the year of application.

In 1975, there were no significant (d.f.=1, $\underline{X}^2$=1.45) differences in fledging success between sprayed and control areas for mountain bluebirds (table 2). Western bluebirds in sprayed areas fledged an average of 2.8 young per nest for 65.9 percent success compared with 2.1 young or 56.5 percent success in control areas. House wrens nesting in sprayed areas averaged 4.0 young fledged or 66.6 percent compared with 1.5 young per nest or 37.5 percent in control areas.

A chi-square test indicated that the greater fledging success exhibited by western bluebirds and house wrens from sprayed areas was significantly different from control area birds (d.f.=1, $\underline{X}^2$=4.53 for western bluebirds; d.f.=1, $\underline{X}^2$=4.36 for house wrens). These differences were in the wrong direction--i.e., mortality was greater in nonspray areas compared with spray areas. This

can be attributed to the substantial variations among treated and untreated areas.

## NESTLING MORTALITY

There were no nestling mortalities reported for any of the three species in sprayed areas in 1974. Mortalities in the control area were limited to one complete brood of six wrens (Thomas and McCluskey 1974).

Nestling mortality was much higher in 1975 in both spray and control areas (table 3). Predation was the primary cause of these losses.

It seemed possible that deaths attributed to other causes (other than predation) might be related to DDT. To test this, we eliminated the losses from predation from consideration--i.e., we subtracted such losses from the total number of nestlings observed. The resulting figure is referred to as the adjusted total of nestlings observed. A ratio was then derived between the number of nestlings lost to other causes and the adjusted total of nestlings observed. This ratio was compared by bird species between spray and control areas.

No differences were detected between spray and control areas for mountain bluebirds (d.f.=1, $\underline{X}^2$=0.14), western bluebirds (d.f.=1, $\underline{X}^2$=3.35), and all species combined (d.f.=1, $\underline{X}^2$=0.34). Chi-square tests were not possible for the data on house wrens due to occurrence of a zero for an expected value.

## BETWEEN-YEAR COMPARISONS

Because tests indicated no statistical differences between sprayed and control areas in several measures of success in reproduction of mountain bluebirds in 1974 and 1975, we could have concluded that DDT had no effect on reproduction in this species. It could be argued, however, that lower rates of reproduction observed in 1975 than in 1974 were caused by DDT contamination. Therefore, we had to make between-year comparisons and test for differences in successful reproduction in 1975 (table 4).

Mountain bluebirds averaged 5.2 eggs per clutch in 1974 compared with 4.9 in 1975 (table 4). A t-test indicated no significant

Table 3--*Nestling mortality in nonspray and spray areas*

| ecies | Nonspray areas | | | | | Spray areas | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total nestlings | Deaths | | | Survived to fledging | Total nestlings | Deaths | | | Survived to fledging |
| | | Due to predators | Due to other causes | Total | | | Due to predators | Due to other causes | Total | |
| ıtain ebirds | 127 | 27 | 13 | 40 | 87 | 222 | 24 | 23 | 47 | 175 |
| tern ebirds | 115 | 54 | 4 | 58 | 57 | 165 | 46 | 21 | 67 | 102 |
| se as | 8 | 5 | 0 | 5 | 3 | 56 | 5 | 2 | 7 | 49 |
| Total | 250 | 86 | 17 | 103 | 147 | 443 | 75 | 46 | 121 | 326 |

Table 4--*Comparison of combined sprayed and control area samples for mountain bluebirds, northeast Oregon, 1974 and 1975*

| Year | N (eggs) | Average clutch (number of eggs) | Average hatch (number of eggs) | Percent hatch | Average number fledged | Percent fledged |
|---|---|---|---|---|---|---|
| 1974 | 309 | 5.2 | 4.9 | 93.8 | 4.9 | 100.0 |
| 1975 | 434 | 4.9 | 4.0 | 82.3 | 2.9 | 73.1 |

differences (d.f.=144, $\underline{t}$=1.46) in clutch size between years for this species.

A comparison of hatching success for mountain bluebirds revealed 93.8 percent in 1974 and 82.3 percent in 1975, significantly lower (d.f.=1, $\underline{X}^2$=21.10) in 1975 than in 1974 according to a chi-square test.

Fledging success between years for mountain bluebirds declined from 100 percent (4.9 young per nest) in 1974 to 73.1 percent (2.9 young per nest) in 1975, a significant difference (d.f.=1, $\underline{X}^2$=90.87) as indicated by a chi-square test.

Some nest boxes were paired between years and some were not. We assumed that the samples at both times were independent random samples. Differences occurring between years could be attributed to either residual effect or yearly effect from climatic differences or both. These potential causes of differences are confounded and cannot be statistically reported.

## RATE OF NESTLING DEVELOPMENT

We compared the average number of days to fledging for mountain bluebirds and western bluebirds nesting in sprayed areas and control areas in 1974 to determine if DDT applications affected nestling growth by reducing the insect food base. A $\underline{t}$-test comparison between sprayed and control areas indicated that the average number of days to fledging for mountain bluebirds and western bluebirds was not significantly different (table 5) (d.f.=35, $\underline{t}$=1.12 for mountain bluebirds; d.f.=35, $\underline{t}$=0.68 for western bluebirds).

Table 5--*Average number of days to fledging of nestling mountain and western bluebirds in sprayed and control areas in northeast Oregon, and 95-percent confidence interval, 1975*

| Species | Sample size (nests) | Mean number days to fledging |
|---|---|---|
| Mountain bluebirds (sprayed area) | 31 | 18.2±0.60 |
| Mountain bluebirds (control area) | 15 | 17.5±0.80 |
| Western bluebirds (sprayed area) | 24 | 19.3±1.0 |
| Western bluebirds (control area) | 10 | 18.8±0.90 |

## Nestling Weight Gains

Mountain bluebirds and western bluebird nestlings of known age from sprayed and control areas were weighed at 1- to 4-day intervals in 1975 so we could document the rate of weight gain (table 6). An F-test comparison of mean daily nestling weights between sprayed and control areas for both species indicated no significant differences (d.f.=35, F=0.004 for mountain bluebirds; d.f.=35, F=0.008 for western bluebirds).

Table 6--*Mean body weights of nestling mountain bluebirds and western bluebirds in sprayed and control areas, northeast Oregon, 1975*

| Age (days) | Sprayed areas | | | | | | Control areas | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight of mountain bluebirds | N | $S^2$ | Weight of western bluebirds | N | $S^2$ | Weight of mountain bluebirds | N | $S^2$ | Weight of western bluebirds | N | $S^2$ |
| | Grams | | | Grams | | | Grams | | | Grams | | |
| 1 | 3.1 | 9 | 0.38 | 2.9 | 14 | 0.10 | 3.1 | 2 | 0.05 | 2.5 | 4 | 0.50 |
| 2 | 4.4 | 5 | .77 | 4.6 | 4 | .27 | 5.1 | 3 | .27 | 3.4 | 1 | -- |
| 3 | 6.8 | 6 | .22 | 5.2 | 3 | 4.33 | 7.3 | 1 | -- | 6.0 | 3 | 1.50 |
| 4 | 10.1 | 6 | 9.15 | 9.6 | 8 | 1.41 | 10.5 | 3 | 1.81 | 8.4 | 3 | 2.65 |
| 5 | 14.2 | 5 | 7.74 | 10.7 | 6 | 7.06 | 14.0 | 1 | -- | 11.7 | 3 | 4.95 |
| 6 | 15.6 | 2 | 10.62 | 14.8 | 7 | 8.66 | 16.3 | 3 | 4.56 | 14.2 | 3 | 2.93 |
| 7 | 17.9 | 9 | 9.98 | 16.2 | 9 | 5.62 | 19.3 | 1 | - | 16.3 | 2 | 4.05 |
| 8 | 23.4 | 5 | 11.83 | 19.9 | 7 | .59 | 21.6 | 3 | 1.57 | 20.4 | 5 | 3.97 |
| 9 | 25.6 | 6 | 6.55 | 21.3 | 6 | 4.75 | 23.4 | 2 | 1.41 | 24.2 | 4 | 16.33 |
| 0 | 25.8 | 4 | .24 | 23.3 | 6 | 5.57 | 27.2 | 2 | 13.60 | 24.3 | 2 | 7.50 |
| 1 | 28.0 | 4 | 2.36 | 23.3 | 4 | 6.18 | 26.0 | 2 | 2.50 | 24.8 | 3 | 4.95 |
| 2 | 28.7 | 10 | 3.06 | 26.7 | 6 | 1.82 | 27.4 | 4 | 9.83 | 25.5 | 3 | 5.25 |
| 3 | 29.1 | 4 | 2.04 | 27.1 | 5 | 7.78 | 28.0 | 1 | -- | 26.5 | 3 | 4.75 |
| 4 | 28.3 | 4 | 1.10 | 27.0 | 4 | 1.51 | 30.3 | 1 | -- | 26.6 | 3 | .66 |
| 5 | 27.9 | 3 | 1.05 | 29.1 | 6 | .62 | 28.4 | 2 | .08 | 26.8 | 3 | 3.10 |
| 6 | 28.7 | 4 | 6.01 | 27.4 | 6 | 1.73 | 28.8 | 1 | -- | 27.1 | 4 | .56 |
| 7 | 28.5 | 2 | .41 | 28.7 | 3 | 15.08 | 27.5 | 1 | -- | 25.6 | 2 | 2.60 |
| 8 | 27.0 | 2 | 6.25 | 26.5 | 2 | .50 | 28.0 | 1 | -- | 25.1 | 2 | 1.30 |

1/ 8 nests of mountain bluebirds and 10 nests of western bluebirds from control areas and nests of mountain bluebirds and 25 nests of western bluebirds from sprayed areas.

## Discussion

The application of DDT in 1974, after nearly all clutches were completed, could not have affected clutch size or egg viability for the three study species. It could have affected hatching success by altering adult survival or behavior.

The observed difference in clutch size for house wrens (table 2) was caused by predators' removing one or more eggs from each nest in control areas; this caused a loss of a greater proportion of the sample. There was no known nest predation in 1974, but more frequent observations in 1975 indicated that some egg losses to predators could have occurred with little or no obvious nest destruction.

If success in reproduction was affected by DDT in 1974, it would have had to be in terms of adult or nestling mortality. Because no dead adults or nestlings were observed on sprayed areas, fledging success was 100 percent (table 2).

Records of observations of mountain and western bluebirds 1 year after application of DDT were designed to disclose longer term impacts of DDT on success in reproduction.

Clutch sizes for all three species studied in 1975 were not

significantly different between sprayed and control areas, indicating that DDT apparently had not affected egg production.

The significant differences in hatching success between sprayed and control areas in 1975 for western bluebirds and house wrens probably were not caused by DDT because greater hatching success occurred in sprayed areas (table 2). Likewise, the significant differences in fledging success for western bluebirds and house wrens in 1975 were due to greater fledging success in sprayed areas than in control areas. It could be argued that the superior success in reproduction shown in nests in sprayed areas may have been the result of a DDT enhancement effect (Heath et al. 1969). If, however, this was the case, then fledging success for birds in sprayed areas in 1974 should also have been enhanced since this was the period when low levels of DDT were most available. The observed significant difference in fledging success for house wrens in 1974 was caused by the loss of a complete brood from a control area and not by greater fledging success of birds in sprayed areas. The observed difference for house wrens and western bluebirds in 1975 was attributed to a type 1 error (Snedecor and Cochran 1967, p. 27). One entire house wren clutch of six eggs failed and five nestlings in the only remaining nest were preyed upon. This left only three nestlings to fledge from a sample of eight nestlings. The loss of 54 nestlings to predators in control areas compared with 48 in sprayed areas accounted for the observed difference in western bluebird fledging success. This is reasonable supportive evidence that the superior success in reproduction reported for house wrens in 1974-75 and western bluebirds in 1975 from sprayed areas was not caused by DDT enhancement.

## ADULT AND NESTLING HOMING BEHAVIOR

For us to monitor impacts of DDT on reproduction of mountain and western bluebirds and house wrens 1 year after spray applications, the living adults and nestlings had to demonstrate reasonable fidelity for breeding areas each year. Fidelity to former breeding areas was not well documented for mountain bluebirds or western bluebirds. Passerine species in general, however, show a marked tendency to return to the same locality in successive breeding seasons (Farner 1945, Uchida 1932). Powers (1966, p. 364) determined that three (42.8 percent) of the adult mountain bluebirds banded during the 1st year of this study returned to breed on his 136-ha (336-acre) study area the following year. During the second year of banding, Powers (1966) observed that three (25 percent) banded adults returned to his study area. These included one adult female which returned to breed for the second consecutive year. Powers (1966, p. 364) commented:"...three of the five returning adults, one male and two females, nested in the boxes they had previously occupied, and the others nested very close to their former nesting territori indicating strong fidelity to the nesting area." Several investigators (Laskey 1940, Krug 1941, Thomas 1946) determined that the number of adult eastern bluebirds returning to former breeding areas ranged between 36 and 60 percent. This figure would actually represent a larger percentage of the number of

birds still available 1 year later if corrections for annual mortality were made. Annual mortality is generally in excess of 50 percent of the adult population (Lack 1954).

Homing for birds banded as nestlings is generally less precise than for adults, but returns to the same general area can be expected (Nice 1937). Observations on starlings *(Sturnus vulgaris)* (Kluijver 1933), tree swallows *(Iridoprocne bicolor)* (Low 1934), barn swallows *(Hirundo rustica)* (Uchida 1932), and song sparrows *(Melospiza melodia)* (Nice 1937, p. 189) indicated that 1.5-12.6 percent of the birds banded as nestlings returned to former nesting areas to breed. Farner (1945) and Hickey (1943) concluded that homing for 1st-year-breeding robins *(Turdus migratorius)*, a species closely related to bluebirds, was definitely not random, but that 70-74 percent of the surviving young returned to breed within a 16- to 40-km (10- to 25-mi) radius of the place where they hatched. Similar data were reported for bank swallows *(Riparia riparia)* and song sparrows (Bergstrom 1951, Nice 1937).

Homing for house wrens was thoroughly studied by Kendeigh (1941). He estimated that 19 percent of the birds banded as adults returned to breed 1 year later and that 10 percent of the birds banded as nestlings returned to breed within 3.2-km (2-mi) radius of their natal nest.

These banding figures were based on the number of young banded with no adjustments for annual mortality which may be as high as 75 percent (Ricklefs 1973). Although specific data on fidelity to nest site is lacking for bluebirds banded as nestlings, the information available on other related species as well as on adult bluebirds indicates that 1st-year-breeding bluebirds would demonstrate reasonable nest-site fidelity. Therefore, the birds observed breeding on study areas in 1975 were likely either adults that nested in the same areas in 1974 or nestlings reared in the areas in 1974.

## BETWEEN-YEAR COMPARISONS

The significant difference in hatching success between years for mountain bluebirds probably was not caused by DDT since hatching success was greater in sprayed areas rather than in control areas. The reason for the difference in hatching success between years is not known. Observed hatching rates in 1975 possibly were significantly lower because of increased bird densities in both sprayed and control areas. White and Wolfenden (1973) observed significantly lower occupancy rates for eastern bluebirds but greater success in reproduction the 1st year nest boxes were erected than the 2d year. They felt that the decline in reproduction observed the 2d year of their study could be attributed to greater social pressure resulting from increased density. Information from this and other studies indicates that hatching success in 1975 was usually greater for all three species than was previously reported (table 7). The 11.5-percent difference in hatching success observed between years for mountain bluebirds in this

Table 7--*Data on reproduction from nest box studies of mountain bluebirds, western bluebirds, and house wrens*

| Author | Species | Sample (eggs) | Average clutch (number of eggs) | Average hatch (number of eggs) | Percent hatched | Average number fledged | Percent fledged |
|---|---|---|---|---|---|---|---|
| Powers (1966) | Mountain bluebird | 104 | 4.9 | 3.8 | 76.9 | 2.9 | 76.3 |
| Miller (1970) | Mountain bluebird | 106 | 4.8 | 3.3 | 67.0 | 2.8 | 88.1 |
| Prigge (1975) | Western bluebird | 481 | 5.1 | 3.3 | 65.3 | 2.5 | 74.2 |
| Kendeigh (1941) | House wren | 6,773 | 6.4 | 5.3 | 82.3 | 4.2 | 79.0 |

study was, considerably lower than the 32.4-percent between-year difference observed by Powers (1966, p. 359). It is not unreasonable, therefore, to attribute the difference in hatching success between 1974 and 1975 to between-year variation.

Weather also may have been an important factor affecting hatching success in 1975. A comparison of weather conditions for June, the principal month of clutch establishment and hatching for the three species, indicated that June 1975 was colder and wetter than June 1974 (table 8). Data collected at Meacham, Umatilla County, Oregon, an area representative of the study areas, indicated that the mean monthly temperature for June 1974 was 1.4°C (2.5°F) lower than the 30-year average and precipitation was 0.97 cm (0.4 in) above normal (table 8). Reports by Criddle (1927), Musselman (1939), Miller (1970), and Pinkowski (1975) revealed that cold-wet weather conditions often caused adult female bluebirds to leave their eggs for long periods, resulting in partial or total failure of the eggs in those nests to hatch. Scott and Lane (1974) reported that 80 percent of the first nests of mountain bluebirds

Table 8--*Average monthly temperature and precipitation for June 1974-75 and 30-year average (1940-70), Meacham, Oregon*[1/]

| Year | Monthly average temperature | Monthly average precipitation |
|---|---|---|
| | Degrees Celsius | Centimeters |
| 1974 | 15.2 | 4.47 |
| 1975 | 11.0 | 6.35 |
| 30-year average, 1940-70 | 12.4 | 5.38 |

[1/] Data derived from National Oceanic and Atmospheric Administration, Meacham, Oregon, station.

failed after a 2-day period when mean daily temperatures of 7.2°C (45°F) and 12.7°C (55°F) were accompanied by 4.4 cm (1.7 in) of precipitation.

Adverse weather conditions and predation were considered responsible for the lower fledging success in 1975.

Mortality resulting from colder than normal weather between June 15 and June 29, 1975 is evident in figure 3. Of 60 nestlings lost to causes other than predation, 53 or 84.1 percent died when mean daily temperatures were below the 30-year average for that day (fig. 4). A period of below-normal temperatures coincided with hatching of the eggs in the majority of nests on the study areas and probably increased the severity of the weather effect. Passerine young are most susceptible to adverse weather conditions until they are 9-10 days old (O'Connor 1975). Scott and Lane (1974) noted that nearly all the dead nestlings they discovered after a severe storm were 1-7 days old. Lane and Burton (1974) and Scott (1974) determined that severe weather conditions reduced the number of young fledged per nest by as much as 50-83 percent.

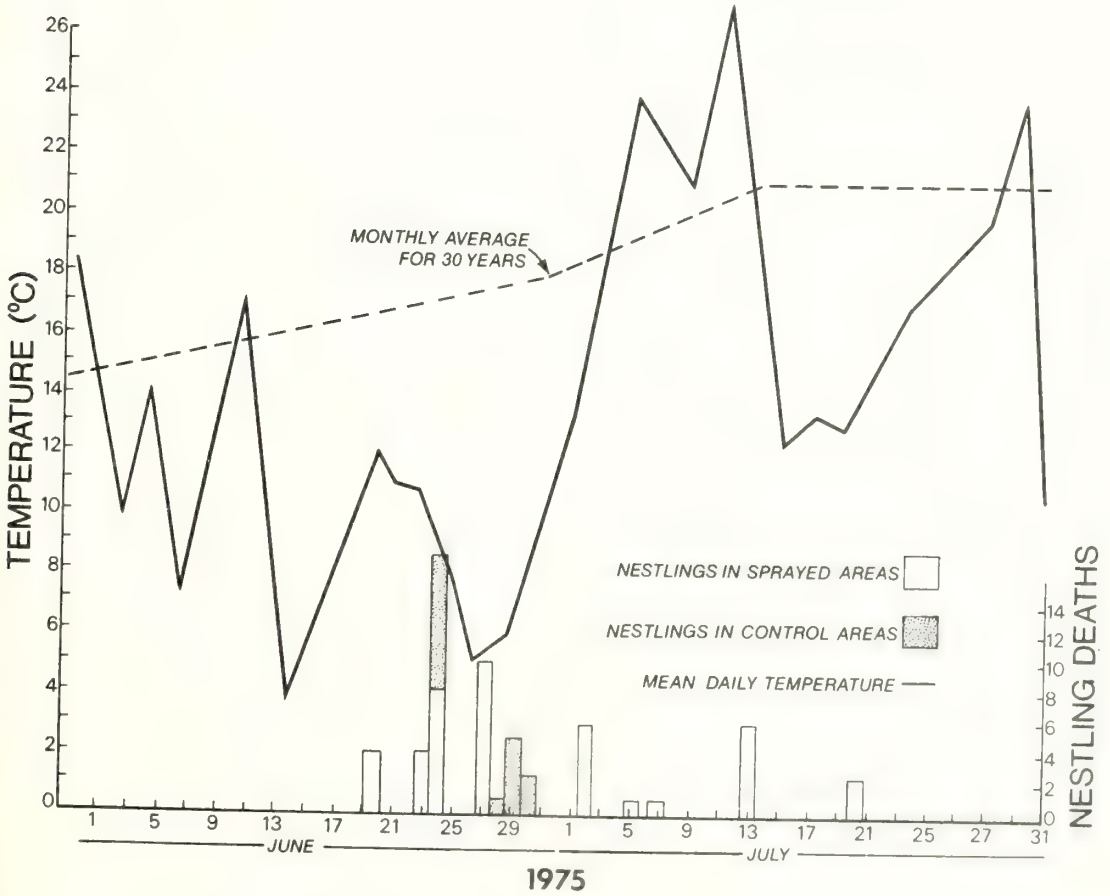


*Figure 3.--Average daily temperature, 30-year monthly average temperature, and combined nestling mortality from sprayed and control areas in northeast Oregon, 1975.*

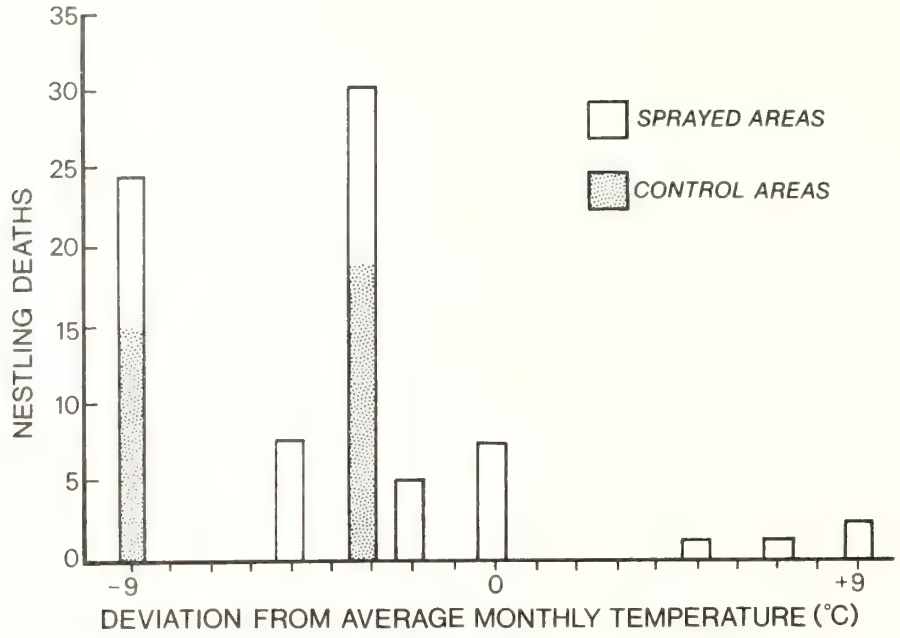


*Figure 4.--Mortality of bluebird and house wren nestlings in northeast Oregon in 1975 in relation to the deviation of the daily average temperature for June and July from the 30-year average temperature.*

Predation was a major cause for the decline in fledging success for all three species in 1975 (table 3). Fifty-one nestlings or 59 percent of all mortality that occurred for mountain bluebirds was caused by predators. Western bluebird losses were greater, with a loss of 100 nestlings or 82 percent of all mortality attributable to predation. House wren mortality attributable to predation accounted for 10 nestlings or 83 percent of the nestlings that died.

The cause of increased predation in 1975 was attributed to more frequent examinations of the nests and their contents and to a larger available sample of occupied nest boxes. Examination of nest boxes at more frequent intervals (2-6 days) in 1975 often caused considerable disturbance of adult birds around the nest. Wilson (1966) determine that the low nesting success for 17 bird species he studied was caused by frequent human activity around the nests. Studies of nest predation in waterfowl indicated that many predators were able to locate nests by movements of adult birds around the nest site (Hammond and Forward 1956).

Three mammal species observed preying on bluebirds and house wrens during this study were the yellow pine chipmunk *(Eutamius amoenus)*, red squirrel *(Tamiasciurus hudsonicus)*, and weasels *(Mustela frenata, M. erminae)*. It was not known if weasels could recognize nest boxes as a source of food or if nest disturbances by the observers allowed weasels to locate nests more easily. In several cases, two or three occupied nest

oxes in sequence were preyed pon, indicating that the weasels ay have associated the nest box ith food and learned to search hem systematically.

Egg and nestling losses ttributed to squirrels and hipmunks appeared to be related o cavity investigation for ossible nest sites. Subsequent bservations on destroyed nests evealed that many had additional esting material added to the ox by squirrels and chipmunks. n several cases sciurid litters ere reared in nest boxes.

Based on the methods used, he results of this study indiated that DDT applied at 0.84 g/ha (0.75 lb/acre) had neither n immediate effect on nestling urvival nor a 2d-year impact n clutch size, hatching, or ledging success for mountain luebirds, western bluebirds, nd house wrens. These results hould not, however, be used to ssign DDT a role as a harmless ontaminant in our environment. pplications of DDT at dosage evels which apparently did ot disrupt success in reproduction of bluebirds and house rens still contribute to DDT esidue in the environment and an be passed on through the ood web.

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# *Appendix*

## LEGAL DESCRIPTION OF RIDGES WHERE SPRAY AND CONTROL AREA BOXES WERE LOCATED

| Ridge | Township | Range | Sections |
|---|---|---|---|
| Spray areas: | | | |
| Horseshoe I | 1 N | 36 E | 7, 18, 19, 20 |
| Horseshoe II | 1 N | 35 E | 3, 10, 11, 13, 14 |
| Powatka | 3 N | 43 E | 9, 12, 22, 27, 32, 33 |
| McAllister I | 3 N | 44 E | 18, 19, 30, 31 |
| McAllister II | 2 N | 44 E | 6 |
| McAllister II | 2 N | 43 E | 1, 12, 13, 24, 25, 36 |
| Control areas: | | | |
| Fox Prairie | 1 S | 36 E | 35, 36 |
| Y-Ridge | 2 S | 37 E | 5, 6 |
| Interstate 80 N | 2 S | 36 E | 21, 27, 28 |
| Spring Creek | 2 S | 36 E | 27, 34 |
| Sled Springs | 3 N | 44 E | 35, 36 |
| Starvation Ridge | 2 N | 44 E | 13, 24, 25 |

GPO 985-159

McCluskey, D. Calvin, Jack Ward Thomas, and E. Charles Meslow. 1977. Effects of aerial application of DDT on reproduction in house wrens and mountain and western bluebirds. USDA For. Serv. Res. Pap. PNW-228, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

No significant adverse effect on reproductive success of mountain bluebirds *(Sialia currucoides)*, western bluebirds *(S. mexicana)*, and house wrens *(Troglodytes aedon)* was detected after aerial application of DDT at a rate of 0.84 kilogram per hectare. The 2-year study determined the fate of 656 eggs within the spray area and 711 eggs within the control area.

KEYWORDS: Pesticide side effects, birds, mountain bluebirds, western bluebirds, house wrens, DDT, spraying (aerial).

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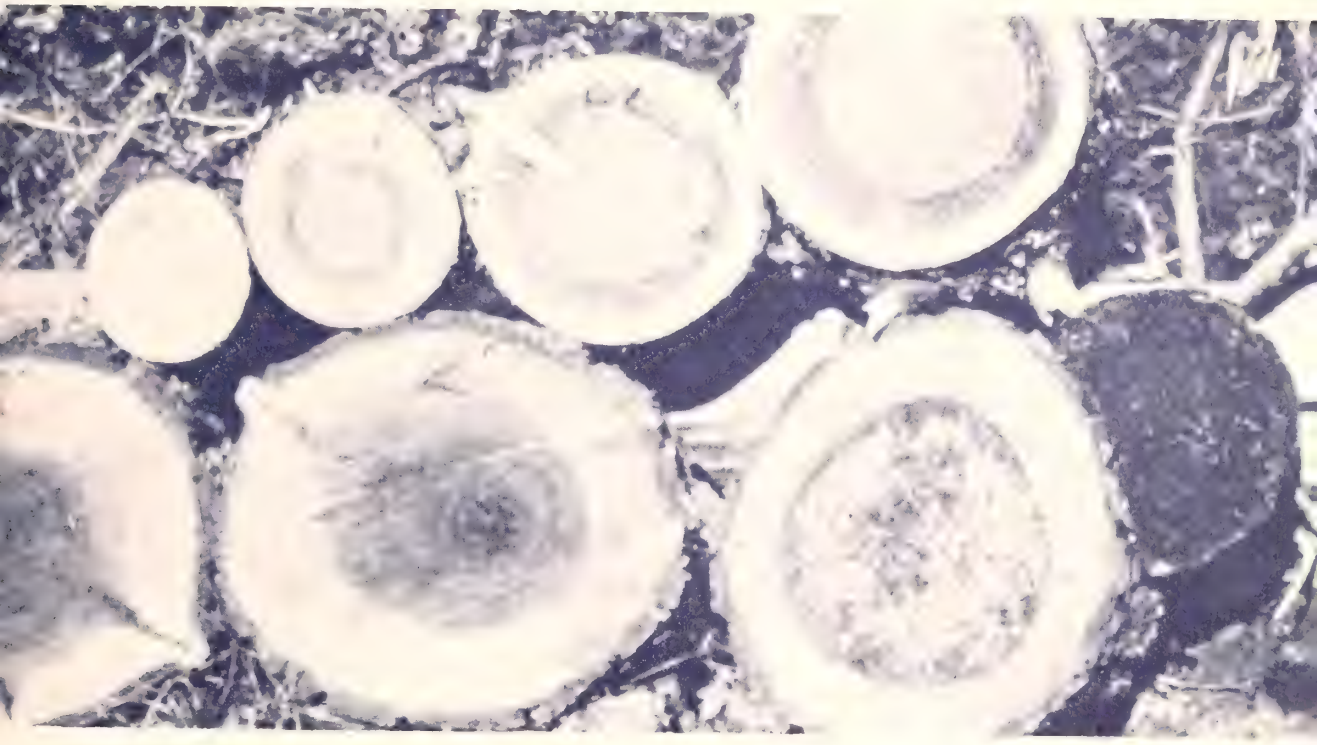
USDA FOREST SERVICE RESEARCH PAPER PNW-229
1977

# Decay of Grand fir



## in the Blue Mountains of Oregon and Washington

Paul E. Aho

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U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

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## Metric Equivalents

| | |
|---|---|
| 1 inch | = 2.54 cm |
| 1 foot | = 0.3048 m |
| 1 cubic foot | = 0.028 32 $m^3$ |
| 1 acre | = 0.4047 ha |

breast height = 4.5 feet = 137.2 cm

# *DECAY OF GRAND FIR IN THE BLUE MOUNTAINS OF OREGON AND WASHINGTON*

*Reference Abstract*

Aho, Paul E.
1977. Decay of grand fir in the Blue Mountains of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-229, 18 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A total of 1,090 grand firs on 65 plots in 11 areas of the Blue Mountains of Oregon and Washington were studied for decay and other defects. Grand fir was highly defective in comparison with its associated species in the mixed conifer types. Decay reduced the net board-foot volume of grand fir in the study trees by one-third. Other types of defects raised the loss in board-foot volume to nearly 40 percent. Decay increased progressively with tree age and diameter, with more than 90 percent of the total cubic- or board-foot decay volume caused by white rot fungi. Defect was also related with early suppression of grand fir.

KEYWORDS: Fungi (-wood deterioration, volume (merchantable), grand fir, Indian paint fungus, Blue Mountains--Oregon, Blue Mountains--Washington.

*RESEARCH SUMMARY*

*Research Paper PNW-229*

*1977*

A total of 1,090 grand firs on 65 plots in 11 areas in the Blue Mountains were studied for decay and other defects. Grand fir was highly defective in comparison to its associated species in the mixed conifer types. Decay reduced the net board-foot volume of grand fir study trees by one-third. In addition, other types of defects and sound volume lost in cull logs resulted in nearly 40 percent unmerchantable grand fir board-foot volume. Decay varied considerably among study areas and even among plots within individual localities.

Decay increased progressively with tree age and diameter. It is not recommended that defect factors based on age or diameter classes be developed for use by cruisers, because of the wide variation in decay in individual age or diameter classes. Pathological rotation age was determined to be 125 to 150 years. Older stands will probably have defect levels which would be unacceptable to forest managers and which should be removed for better site utilization.

More than 90 percent of the total cubic- or board-foot decay

volume was caused by white rot fungi. Fourteen fungi were identified. Only four were of major significance; *Echinodontium tinctorium*, *Pholiota* sp., *Hericium abietis*, and *Fomitopsis annosa*. *Echinodontium tinctorium* alone was associated with more than 48 percent of all infections and 78 percent of the board-foot decay volume. Branches were apparently the major infection court for this fungus. *Pholiota* sp. and *H. abietis* infected trees through injuries. Trunk wounds, especially basal wounds, were most important. *Fomitopsis annosa* attacked grand firs mainly through the roots (70 percent), but also was associated with wounds including dead and broken tops.

Defect was also related with early suppression of grand fir. Although data was limited in some age classes, trees badly suppressed early in life appeared to be more defective than faster growing trees. Additional studies are needed to determine the potential future decay hazard if suppressed grand fir reproduction is used to form new forest stands.

## Introduction

The associated species, grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), western larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmanii* Parry), subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), and lodgepole pine (*Pinus contorta* Dougl.) generally form mixed, uneven-aged stands above the upper elevational limits of the ponderosa pine types in the Blue Mountains. These stands occur on more than a third of the commercial forest land and represent nearly half of the growing stock and board-foot volume on all ownerships.[1/] Many authors report that both grand and white fir (*A. concolor* (Gord. and Glend.) Lindl.) occur in the Blue Mountains, although Maul (1957) does not include that area in the natural range of white fir. The Blue Mountains are reported to be one of five climatic provinces of grand fir (Müller 1938). This morphologically variable complex, which will be referred to here as grand fir, has been attributed to ecological factors by Müller (1938). Grand fir, a major component of these types, has many desirable characteristics: it reproduces well, is a good competitor, is tolerant, and if not suppressed too long, grows rapidly when released. Its existing large volumes are suited for both pulp and lumber (Hubert 1955).

In the past, other species were cut in preference to grand fir; consequently, most stands of this species are mature or overmature and commonly highly defective, mainly because of decay. Productivity would be significantly increased if defective stands were harvested. Utilization and management guidelines for grand fir based on defect and decay hazard are needed for optimal use of this resource. Most decay in grand fir has been attributed to the Indian paint fungus, *Echinodontium tinctorium* Ell. and Ev. (Hubert 1955). Maloy (1967) has made an excellent, comprehensive literature review on the Indian paint fungus, and results of several significant studies have been reported since that date (Aho 1976, Aho and Hutchins 1977, Etheridge et al. 1972, Hudson 1972, Maloy 1968, Maloy and Robinson 1968). This paper will emphasize *E. tinctorium* because of the demonstrated major impact of this fungus on management and utilization of grand fir.

Methods for accurate estimation of defect in grand fir trees in the Blue Mountains have been published (Aho 1966, Aho 1974). This paper presents a more comprehensive account of decay and other defects applicable to management of grand fir in the Blue Mountains.

## Methods

Sixty-six circular 1/5-acre plots were systematically selected in mature or overmature stands in 11 widely spaced localities in the Umatilla, Wallowa-Whitman, and Malheur National Forests (fig. 1). All 5-inch d.b.h. and larger trees were examined while standing. Tree species, inner bark color of grand firs, d.b.h., crown class, and condition, and the location and description of possible fungal infection courts and indicators of decay were recorded before trees were felled,

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[1/] Forest Survey data on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

*Figure 1.--Approximate location of grand fir study areas.*

dissected, and examined for decay and other defects. Procedures for dissection and cubic- and board-foot volume measurement of trees and defect have been described previously (Aho 1966, Aho 1974).

Two ring counts were made at stump height which was usually at 1 foot above ground. The first was a total count to determine tree age, and the second was made from the pith out a radius of average growth (not the slowest or fastest areas of ring growth), to a distance of 3 inches to detect early suppression. Blocks approximately 3 inches in size were obtained from most decay columns in study trees to determine the fungi present. In the first study locality, isolations were not made from some grand firs bearing *E. tinctorium* conks because it was assumed that decay in those trees was caused by that fungus. Each evening, cultures were made by aseptically placing decayed wood chips on 2-percent malt agar slants in test tubes. Inoculated tubes were incubated at room temperatures. Fungi isolated were identified on the basis of cultural characteristics by the author and mycologists Ross W. Davidson and Frances L. Lombard, Forest Disease Laboratory, Laurel, Maryland.[2/]

Covariance analysis was used to determine whether there were significant differences between cubic-foot decay percentages in relation to tree age for trees with grand and white fir-like barks (Chapter 14, Snedecor and Cochran 1967). Formal statistical analyses were not applied to other data in this study.

## Results and Discussion

*Comparison of defect among species.*--Six tree species were studied on the 66 plots. A total of 1,861 trees were examined for various defects. Grand fir, the most defective species comprising the commercial portion of the upper slope or mixed conifer types, made up nearly 60 percent of the sample. Table 1 summarizes the basic data for each species by pole and sawtimber size trees. Decay in sawtimber size grand fir was responsible for a loss of 14 percent of its gross merchantable cubic-foot volume and 33 percent of its board-foot volume. Defect in sawtimber size Engelmann spruce, Douglas-fir, and western larch, the other important commercial species in the mixed conifer types, is relatively small compared to grand fir. Decay caused a loss of 5.4 percent of the gross cubic volume and 11.1 percent of the gross board-foot volume of Engelmann spruce, 4.0 percent of the cubic- and 10.1 percent of the board-foot volume of Douglas-fir, and only 2.6 and 5.5 percent of the cubic- and board-foot volumes of western larch. Although only 26 sawtimber size subalpine firs were sampled, defect losses in this species were of the same magnitude as those in grand fir.

When cull rules for logs were applied and other types of defect deductions were included with decay, slightly more than 38 percent of the gross merchantable board-foot volume of grand fir was culled. Most of the additional defect losses were

2/ Now called the Center for Mycology Research and presently located at the Forest Products Laboratory, Madison, Wisconsin.

Table 1--Summary of basic data for associated species on CP study plots in 11 localities in the Pine Mountains

| Species | Tree d.b.h. 5.0-10-9-inch | | | | | | Tree d.b.h. 11.0-inch and greater | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tree basis | Average | | | Cubic-foot volume | | Tree basis | Average | | | Cubic-foot volume | | Board-foot volume | |
| | | Age | D.b.h. | Height | Gross merchantable | Decay | | Age | D.b.h. | Height | Gross merchantable | Decay | Gross merchantable | Decay | All defect 1/ |
| | Number | Years | Inches | Feet | Cubic feet | Percent | Number | Years | Inches | Feet | Cubic feet | Percent | Board feet | - - Percent - - | |
| Grand fir | 411 | 134 | 7.8 | 46 | 2,815.1 | 7.2 | 679 | 190 | 20.7 | 90 | 61,717.0 | 14.1 | 330,844 | 33.3 | 38.3 |
| Engelmann spruce | 141 | 119 | 7.5 | 52 | 1,153.2 | 3.3 | 151 | 154 | 16.9 | 93 | 10,166.5 | 5.4 | 50,345 | 11.1 | 11.8 |
| Douglas-fir | 64 | 134 | 8.3 | 55 | 541.9 | 1.8 | 160 | 222 | 21.4 | 97 | 14,644.1 | 4.0 | 77,866 | 10.1 | 10.6 |
| Western larch | 21 | 75 | 6.8 | 54 | 119.2 | 2.8 | 90 | 194 | 21.4 | 110 | 9,852.7 | 2.6 | 56,030 | 5.5 | 5.8 |
| Subalpine fir | 339 | 152 | 8.0 | 50 | 288.0 | 13.4 | 26 | 151 | 13.8 | 79 | 869.2 | 10.9 | 3,648 | 30.2 | 33.0 |
| Lodgepole pine | 63 | 108 | 7.5 | 55 | 540.6 | .3 | 16 | 139 | 14.0 | 85 | 696.9 | 5.3 | 3,059 | 15.2 | 15.2 |

1/ In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

caused by shake and frost cracks which were associated with wetwood, usually in the butt log. Wetwood is a condition of unknown origin in which the heartwood is excessively wet. With the exception of subalpine fir, the other species seldom had wetwood or its associated defects, shake, or frost cracks. Thus, decay caused nearly all the defect in Engelmann spruce, Douglas-fir, western larch, and lodgepole pine.

Defect percentages shown in table 1 may be somewhat higher than actual average board-foot defect in these species in the Blue Mountains. Most plots were in sale areas, which are generally located in the older, more defective stands.

*Distribution of decay in grand fir by study location.*--There was wide variation in decay losses in sawtimber and pole size grand fir from study locality to locality (table 2). Cubic-foot decay of trees greater than 11-inch d.b.h. ranged from less than 1 percent at Deardorff Ridge to 32 percent at Mount Nebo. In 6 of the 11 study areas , board-foot decay in sawtimber trees exceeded 40 percent of total gross merchantable volume. Decay in pole size trees (5.0-10.9 inch d.b.h.) also varied from locality to locality, but not to the extent it did in sawtimber trees. Cubic decay varied from less than 1 percent at Deardorff Ridge to nearly 14 percent at Texas Bar. Decay variation in both pole and sawtimber size trees could not be explained solely on the basis of age. For example, in the Round Mountain locality, sawtimber averaged 157 years and decay was 21.6 percent of gross board-foot volume. In the Summit Spring area, average age was 153 years but decay was 55.9 percent of the gross board-foot volume.

Decay not only varied among study localities but also from plot to plot in individual localities. For instance, on the 13 plots taken in the Round Mountain study area, board-foot decay in sawtimber trees ranged from less than 1 percent to nearly 50 percent, even though many of the plots were only a few chains apart. Again, the variation could not be explained by average age of trees on the plots.

*Decay variation between grand firs with different bark characteristics.*--According to Müller (1938), grand firs growing on exposed, dry sites will exhibit bark (and needle) characteristics similar to white fir. The inner bark of grand fir is usually reddish to reddish purple while that of white fir is greyish white, resembling that of Douglas-fir. Trees were separated on the basis of inner bark color. There were 644 trees with white fir-like inner bark and 446 with grand fir-like bark. Covariance analysis was used to determine whether or not there were differences in decay in relation to tree age for the two groups. Significant differences (at the 1-percent level) were found in the slopes of the regression surfaces and elevations (means) of the regression lines for the two groups of trees. Cubic-foot decay percents were lower for the grand fir-like trees up to 150 years; but after that age, they increased much more rapidly than for the white fir-like group.

Infection and subsequent decay development may be limited by environmental conditions in dry, exposed sites where trees with white fir-like bark are found. Weir and Hubert (1919) found that total number of trees infected by *E. tinctorium*, live trees with sporophores, and total number of live sporophores were reduced on cutover areas. They suggested that increased light and reduced moisture conditions affect germination and penetration of basidiospores of the Indian paint fungus. Maloy (1963) found that shade was important for survival of *E. tinctorium* sporophores on felled grand firs.

Table 2--*Summary of basic data for grand fir by study localities*

| Study locality and Ranger District | Tree d.b.h. 5.0- to 10.9-inch | | | | | | | Tree d.b.h. 11.0-inch and greater | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basis | | Average | | | Cubic-foot volume | | Basis | | Average | | | Cubic-foot volume | | Board-foot volume | | |
| | Plots | Trees | Age | D.b.h. | Height | Gross merchantable | Decay | Plots | Trees | Age | D.b.h. | Height | Gross merchantable | Decay | Gross merchantable | Decay | All defect[1/] |
| | - - Number - - | | Years | Inches | Feet | Cubic feet | Percent | - - Number - - | | Years | Inches | Feet | Cubic feet | Percent | Board feet | - - Percent - - | |
| Round Mountain, Pendleton | 6 | 12 | 102 | 10.0 | 66 | 179.0 | 8.9 | 13 | 124 | 157 | 23.3 | 98 | 14,152.6 | 9.0 | 78,607 | 21.6 | 27.5 |
| Mount Nebo, Joseph | 7 | 33 | 130 | 7.3 | 40 | 144.9 | 12.5 | 9 | 57 | 219 | 19.9 | 88 | 4,782.3 | 32.0 | 26,628 | 58.9 | 61.4 |
| Abel's Ridge, Pomercy | 5 | 49 | 124 | 8.2 | 55 | 473.0 | 4.0 | 5 | 59 | 194 | 21.0 | 95 | 5,918.1 | 15.8 | 32,405 | 39.4 | 43.4 |
| Swamp Creek #2, Walla Walla | 5 | 14 | 173 | 8.0 | 45 | 120.2 | 4.3 | 6 | 86 | 178 | 22.5 | 108 | 11,321.8 | 7.5 | 64,357 | 18.6 | 21.7 |
| Texas Bar, Ukiah | 6 | 59 | 159 | 7.9 | 42 | 334.0 | 13.8 | 6 | 74 | 211 | 20.4 | 89 | 6,265.7 | 18.0 | 32,640 | 45.0 | 61.3 |
| Summit Spring, Bear Sleds | 6 | 103 | 120 | 7.9 | 53 | 828.7 | 8.5 | 6 | 68 | 153 | 18.1 | 89 | 5,093.9 | 23.0 | 26,656 | 55.9 | 62.2 |
| Wolf Creek, Baker | 7 | 34 | 162 | 7.6 | 39 | 168.3 | 4.0 | 8 | 66 | 209 | 18.8 | 82 | 4,658.6 | 8.2 | 23,526 | 21.1 | 23.6 |
| Trout Farm, Prairie City | 3 | 20 | 206 | 8.0 | 34 | 113.0 | 12.1 | 3 | 35 | 259 | 19.9 | 85 | 2,620.7 | 22.1 | 12,788 | 56.6 | 59.2 |
| Deardorff Ridge, Prairie City | 3 | 39 | 77 | 7.7 | 47 | 264.2 | .2 | 3 | 34 | 103 | 18.9 | 85 | 2,353.0 | .8 | 11,576 | 3.6 | 3.7 |
| Wiley Creek, Long Creek | 3 | 33 | 131 | 6.8 | 30 | 121.6 | 3.4 | 3 | 29 | 200 | 18.0 | 66 | 1,478.8 | 22.4 | 6,572 | 63.7 | 63.7 |
| Onion Spring, Prairie City | 3 | 15 | 179 | 7.6 | 34 | 68.2 | 2.4 | 3 | 47 | 255 | 20.2 | 74 | 3,071.5 | 16.5 | 15,089 | 41.7 | 42.9 |
| Total or average | 54 | 411 | 134 | 7.8 | 46 | 2,815.1 | 7.1 | 65 | 679 | 190 | 20.7 | 90 | 61,717.0 | 14.1 | 330,844 | 33.3 | 38.3 |

[1/] In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

*Decay and total defect in relation to age.*--Decay generally increases in incidence and severity with increasing tree or stand age (Wagener and Davidson 1954). Grand firs in this study were sorted into 50-year age classes and percent decay and defect[3/] determined for each class (fig. 2). Both decay and defect increase with age. Grand fir was reported to be subject to serious decay losses at an early age in Idaho (Hubert 1955, Maloy and Gross 1963) and in the Blue Mountains because of the prevalence of decay in mature and over-mature trees (Boyce 1930). This study, however, indicates that decay and other defects are not a serious problem in young trees nor are they likely to be in future rotations of grand fir under intensive management in the Blue Mountains. Board-foot defect in trees younger than 100 years old was less than 3 percent of total gross volume and slightly more than 13 percent in trees from 100 to 149 years old. Rotation ages over 125 years will probably be uncommon in managed stands of the future. Even under partial cut management, grand fir stands can be kept relatively free of defect for many years provided that logging wounds are held to a minimum on residual trees and wounded and conked trees are removed in intermediate cuts.

Total board-foot defect loss in the 150- to 199-year age class was 32 percent, approximately 47 percent in the 200-249-year age class, and nearly 70 percent for all trees over 250 years old. Removal and utilization of grand fir stands over 250 years old is a serious forest management

[3/] Defect in board foot measure includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

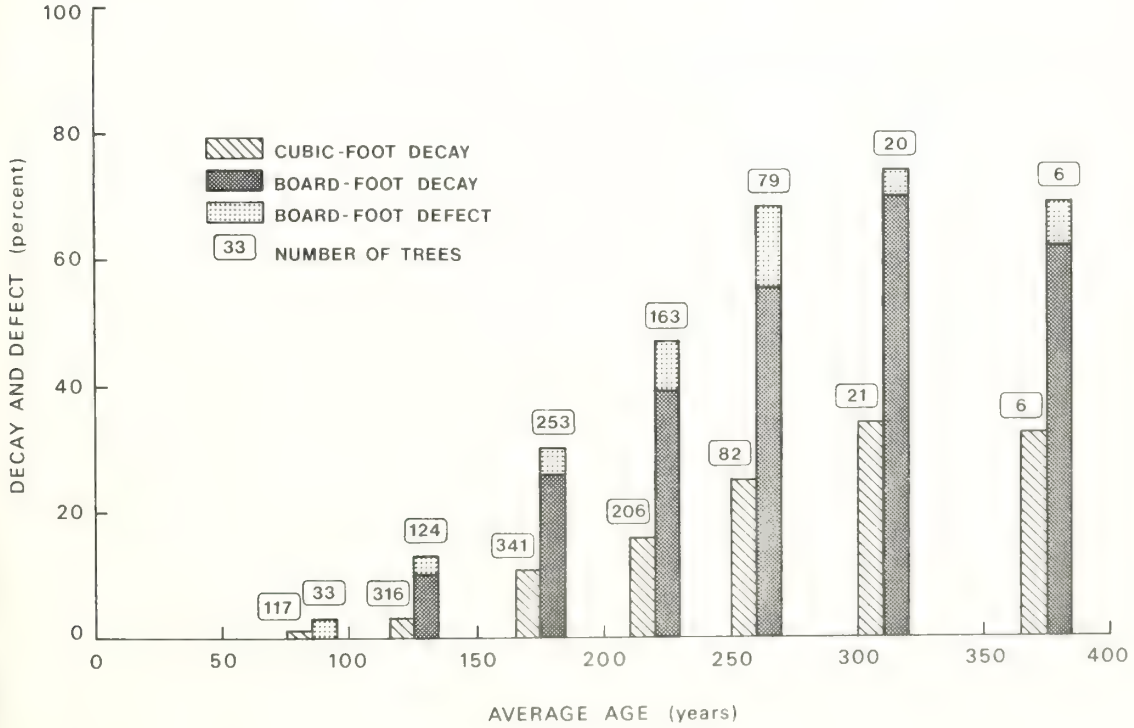


*Figure 2.--Percent of cubic- and board-foot volumes decayed and total board-foot defect in grand fir by 50-year age classes.*

problem in the Blue Mountains. Logging costs are greater in defective than in sound stands; and since both quantity and quality of logs are affected, logging costs may not be recovered.

*Distribution of trees with various amounts of decay within age classes.*-- Defect factors based on tree or stand age are used in presale or inventory cruises (Wagener and Davidson 1954). Since decay is usually correlated with age, this may be a realistic and relatively simple method to use. Grand firs in each 50-year age class were grouped by the amount of decay (percent of their total board-foot volume) they contained (table 3).

for individual trees or stands. Estimation of defect or decisions on which trees to harvest should not be based on age alone, but on a combination of factors as described by Aho (1974).

*Decay in relation to diameter.*-- Since diameter is a function of age, the incidence and severity of decay should also increase with diameter. It may be more practical to develop defect factors for diameter classes than for age, because diameter (d.b.h.) is easy to measure. This has been done successfully for some tree species (Wagener and Davidson 1954). When all grand firs in this study were sorted by d.b.h., decay and defect increased with diameter (table 4). Decay and

Table 3--*Distribution of grand firs with various amounts of board-foot decay by 50-year age classes*

| Age class | Tree basis | Trees by board-foot decay class | | | | | | Board-foot decay volume |
|---|---|---|---|---|---|---|---|---|
| | | No decay | 0.1 to 10 | 11 to 25 | 26-50 | 51-75 | 76-100 | |
| Years | Number | Percent | | | | | | |
| 50-99 | 33 | 97 | 3 | 0 | 0 | 0 | 0 | 1/ |
| 100-149 | 124 | 70 | 9 | 4 | 2 | 6 | 9 | 10.2 |
| 150-199 | 253 | 40 | 10 | 9 | 13 | 11 | 17 | 25.9 |
| 200-249 | 163 | 30 | 7 | 10 | 8 | 17 | 28 | 38.9 |
| 250-299 | 79 | 13 | 8 | 5 | 14 | 23 | 37 | 55.7 |
| 300-349 | 20 | 15 | 5 | 15 | 10 | 5 | 50 | 69.6 |
| 350-399 | 6 | 0 | 17 | 17 | 0 | 33 | 33 | 61.8 |
| 450-499 | 1 | 0 | 0 | 0 | 0 | 0 | 100 | 96.9 |
| Total or average | 679 | 41 | 9 | 8 | 9 | 12 | 21 | 33.3 |

1/ Less than 0.5-percent decay.

There was a progressive decrease in trees without measurable decay from 97 percent in the 50- to 99-year age class to none in the 350- to 399-year age class. There was a general increase in percentage of trees in each defect class with increasing age classes. There is considerable variation in decay in trees in the same age class. Trees in the 100- to 149-year class had an average of 10.2 percent board-foot decay, but 70 percent of the trees were completely free of decay; while 15 percent had less than, and 15 percent more than, 50 percent of their volumes decayed. Defect factors for broad age classes of grand fir are not reliable

defect, however, were high in all diameter classes over 11-inch d.b.h. Each diameter class consisted of a wide range of ages because of suppression. When trees in each diameter class were sorted by age, there was a progressive increase in decay with increasing age. Thus, age more accurately reflects extent of decay than does diameter.

*Distribution of trees with various amounts of decay within diameter classes* The distribution of trees with various amounts of board-foot decay varied within each diameter class (table 5) just as it did with age. Of the 363 trees in the 11.0- to 18.9-inch

Table 4--*Decay and defect related to diameter of grand fir*

| Diameter class | Tree basis | Average age | Decay volume | | All board-foot defect |
|---|---|---|---|---|---|
| | | | Cubic feet | Board feet | |
| Inches | Number | Years | - - - - - - Percent - - - - - - | | |
| 5.0-10.9 | 411 | 135 | 7.1 | 1/ | 1/ |
| 11.0-18.9 | 363 | 174 | 10.8 | 29.1 | 33.7 |
| 19.0-26.9 | 225 | 201 | 12.5 | 30.3 | 37.1 |
| 27.0-34.9 | 75 | 221 | 16.3 | 33.6 | 41.4 |
| 35.0-42.9 | 16 | 251 | 23.9 | 54.2 | 65.9 |
| Total or average | 1,090 | 169 | 13.8 | 33.3 | 38.3 |

1/ Board foot volume is not calculated for pole-size trees.

Table 5--*Distribution of grand firs with various amounts of board-foot decay by diameter classes*

| Diameter class | Tree basis | Trees by board-foot decay class | | | | | | Board-foot decay volume |
|---|---|---|---|---|---|---|---|---|
| | | None | 0.1 to 10 | 11 to 25 | 26 to 50 | 51 to 75 | 76 to 100 | |
| Inches | Number | - - - - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - - - - - | | | | | | |
| 11.0-18.9 | 363 | 47 | 8 | 7 | 6 | 9 | 23 | 29.1 |
| 19.0-26.9 | 225 | 36 | 10 | 10 | 13 | 14 | 17 | 30.3 |
| 27.0-34.9 | 75 | 36 | 8 | 5 | 16 | 15 | 20 | 33.6 |
| 35.0-42.9 | 16 | 0 | 13 | 6 | 6 | 50 | 25 | 54.2 |

diameter class, 47 percent were free of measurable decay, but nearly a third had more than 50 percent of their board-foot volume decayed. Although it may be practical or even justified for timber cruisers to use average defect factors by diameter classes for some species, it would be impractical to do so for grand fir, since inaccurate net volumes would result.

*Decay in relation to early suppression.*--Grand fir is a tolerant species and is often subjected to long periods of suppression and slow growth. There is conflicting evidence in the literature that decay is related to suppression in various tree species (Boyce 1961). To determine the relation of decay to suppression in grand fir, trees were sorted into three arbitrary early suppression classes based on a 3-inch ring count from the pith along a radius of average growth at stump height. Cubic-foot decay percentages for each suppression class were compared by 50-year age classes. Fast growing trees (26-75 rings) in each age class are considerably larger in d.b.h. and height than the moderately fast growing trees (76-125 rings) which are larger than the slowest growing (126+ rings) or most suppressed trees (table 6). Cubic decay as a proportion of total volume of each suppression or growth class ranged from 9.7 percent in the fast growing, to 17.7 percent in the moderately fast growing, to 24.7 percent in the slow growing trees.

Although there were only 10 trees between 100-149 years of age in the slowest growing class (126+ rings), the data suggest that decay is more serious in this class than in the fast and moderately slow growing

Table 6--*Decay in relation to early suppression of grand fir*

| Basic data for suppression classes | Age class (years) | | | | | | | | | T |
|---|---|---|---|---|---|---|---|---|---|---|
| | 50-99 | 100-149 | 150-199 | 200-249 | 250-299 | 300-349 | 350-399 | 400-499 | 450-499 | av |
| 26-75 rings | | | | | | | | | | |
| Tree basis (Number) | 100 | 121 | 159 | 27 | 5 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average 3-inch ring count (Number) | 48 | 60 | 52 | 64 | 63 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average age (Years) | 77 | 123 | 173 | 214 | 278 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average d.b.h. (Inches) | 10.2 | 16.3 | 22.0 | 24.8 | 35.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1 |
| Average height (Feet) | 63 | 85 | 106 | 104 | 106 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average cubic-foot volume ($ft^3$) | 20.0 | 64.3 | 130.9 | 151.7 | 232.2 | 0.0 | 0.0 | 0.0 | 0.0 | 8 |
| Cubic-foot decay (Percent) | 1/ | 4.1 | 10.8 | 15.6 | 24.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 76-125 rings | | | | | | | | | | |
| Tree basis (Number) | 17 | 185 | 137 | 109 | 46 | 14 | 5 | 0.0 | 0.0 | |
| Average 3-inch ring count (Number) | 82 | 94 | 98 | 99 | 106 | 111 | 109 | 0.0 | 0.0 | |
| Average age (Years) | 95 | 123 | 173 | 217 | 271 | 318 | 369 | 0.0 | 0.0 | |
| Average d.b.h. (Inches) | 6.5 | 8.2 | 13.2 | 18.5 | 26.2 | 21.7 | 30.0 | 0.0 | 0.0 | 1 |
| Average height (Feet) | 42 | 48 | 67 | 80 | 101 | 91 | 105 | 0.0 | 0.0 | |
| Average cubic-foot volume ($ft^3$) | 4.2 | 11.3 | 32.0 | 71.2 | 151.2 | 92.0 | 203.7 | 0.0 | 0.0 | 4 |
| Cubic-foot decay (Percent) | 1.9 | 2.7 | 10.2 | 16.2 | 25.0 | 31.9 | 26.3 | 0.0 | 0.0 | 1 |
| 126+ rings | | | | | | | | | | |
| Tree basis (Number) | 0.0 | 10 | 45 | 69 | 31 | 7 | 1 | 0.0 | 1 | |
| Average 3-inch ring count (Number) | 0.0 | 130 | 143 | 152 | 150 | 180 | 162 | 0.0 | 163 | |
| Average age (Years) | 0.0 | 141 | 177 | 223 | 275 | 334 | 390 | 0.0 | 472 | |
| Average d.b.h. (Inches) | 0.0 | 6.4 | 8.2 | 11.8 | 17.6 | 17.6 | 33.8 | 0.0 | 34.5 | 1 |
| Average height (Feet) | 0.0 | 35 | 42 | 59 | 77 | 73 | 2/ | 0.0 | 110 | |
| Average cubic-foot volume ($ft^3$) | 0.0 | 2.1 | 7.9 | 27.2 | 64.0 | 57.4 | 265.6 | 0.0 | 195.9 | 1 |
| Cubic-foot decay (Percent) | 0.0 | 10.0 | 8.7 | 15.6 | 27.3 | 40.7 | 54.7 | 0.0 | 42.2 | 2 |

1/ Less than 0.1-percent decay.

2/ No height because the tree had a broken top.

classes, which are about equally defective. From 150-299 years, decay in the three suppression or growth classes is similar. Although the sample was small, slow growing trees were more defective than the moderately slow growing trees in age classes over 300 years.

Meinecke (1916) reported that up to 150 years of age, decay is most severe in suppressed or slow growing white firs in southwestern Oregon. After 150 years, all trees are equally defective, regardless of suppression or growth rate. Boyce (1961) concluded that "lack of vigor expressed by suppression tends to increase decay in the earlier years in certain species, but as trees grow older this influence disappears, and fast-grown trees may be as much decayed as or even more than slow-grown trees."

These findings, along with those of Etheridge et al. (1972) and Aho and Hutchins (1977) on the mode of infection by the Indian paint fungus, suggest that studies should be undertaken to determine whether or not suppressed grand fir regeneration is infected by decay fungi and subject to serious decay after release and before rotation age.

*Fungi associated with decay.*--Fungi associated with nearly 72 percent of all decay columns in grand fir were identified (table 7). These decay columns accounted for nearly 92 percent of the total board-foot and cubic-foot decay volumes. Although the fungi causing 28.3 percent of the decay columns were unidentified, their impact in terms of volume losses was small.

Although grand fir heartwood was attacked by many fungi, only 14 were identified. Most of the decay was associated with white trunk rot fungi, which were respondible for 62 percent of the total number of infections and nearly 84 percent of the total board-foot decay volume (table 7). Of the white root and butt rots, only *Fomitopsis annosa* (*Fomes annosus*) (Fr.) Karst. caused significant numbers of infections, but associated decay volumes were relatively small.

Table 7--*Fungi associated with decay of grand fir*

| Fungus | Infections | | Average decay volume 1/ | | Percent total decay volume 1/ | |
|---|---|---|---|---|---|---|
| | Number | Percent | Cubic feet | Board feet | Cubic feet | Board feet |
| e trunk rots: | | | | | | |
| *inodontium tinctorium* Ell. & Ev. | 270 | 45.5 | 24.1 | 376 | 72.9 | 70.9 |
| *oliota* sp. | 57 | 9.6 | 10.6 | 167 | 6.8 | 7.9 |
| *ricium abietis* (Weir ex Hubert) K. Harrison | 35 | 5.9 | 9.2 | 143 | 3.6 | 4.2 |
| *ellinus* (*Fomes*) *pini* (Thore ex Fr.) Pilát | 3 | .5 | 22.6 | 248 | .8 | .7 |
| *ylostereum* (*Stereum*) *chailletii* (Pers. ex Fr.) Boid. | 2 | .3 | 1.3 | 24 | 3/ | 3/ |
| *schioporus* (*Polyporus*) *abietinus* (Dicks. ex Fr.) Douk | 1 | .2 | .3 | 8 | 3/ | 3/ |
| *ereum sanguinolentum* Alb. & Schw. ex Fr. | 1 | .2 | .9 | 8 | 3/ | 3/ |
| e root and butt rots: | | | | | | |
| *ritopsis* (*Fomes*) *annosa* (Fr.) Karst. | 30 | 5.0 | 2.5 | 58 | .9 | .7 |
| *yporus tomentosus* Fr. var. *circinatus* (Fr.) Fatory & Maire | 2 | .3 | .5 | 15 | 3/ | 3/ |
| *illariella mellea* (Fr.) Karst. | 3 | .5 | 5.0 | 132 | .2 | .4 |
| *eticium galactinum* (Fr.) Burt | 1 | .2 | .1 | 4/ 0 | 3/ | 4/ 0 |
| trunk rots: | | | | | | |
| *iophora puteana* (Schum. ex Fr.) Karst. | 2 | .3 | 1.8 | 36 | 3/ | 3/ |
| *ochispora raduloides* (Karst.) Rogers | 1 | .2 | 30.7 | 388 | .3 | .4 |
| *ritopsis* (*Fomes*) *pinicola* (Swartz ex Fr.) Karst. | 1 | .2 | .1 | 3 | 3/ | 3/ |
| 2/: | | | | | | |
| *tinctorium* - *Pholiota* sp. | 12 | 2.0 | 38.9 | 515 | 5.2 | 5.6 |
| *tinctorium* - *H. abietis* | 3 | .5 | 25.4 | 502 | .9 | .9 |
| *oliota* sp. - *H. abietis* | 2 | .3 | 6.8 | 132 | .2 | .1 |
| dentified | 168 | 28.3 | 4.4 | 74 | 8.2 | 8.2 |
| or average | 594 | 100.0 | 15.0 | 242 | 100.0 | 100.0 |

1/ Infections in pole and sawtimber size trees are included under cubic-foot measurement, but only infections in trees larger 11.0-inch d.b.h. are included under board-foot measurement.

2/ Fungi associated in mixed infections as determined by cultural techniques.

3/ Less than 0.05 percent of the total cubic- or board-foot decay volume.

4/ No board-foot decay volume because the infection was in a pole-size tree.

There were no identified brown root and butt rots and only four brown trunk rots with insignificant amounts of decay.

Of the 14 identified fungi, only 4 were important in number of infections and decay volumes. These four fungi, *E. tinctorium*, *Pholiota* sp., *Hericium abietis* (Weir ex Hubert) K. Harrison, and *F. annosa*, were commonly isolated from grand firs in Idaho (Maloy 1968, Hudson 1972) and from white fir in southwestern Oregon (Aho 1976). The most important was the Indian paint fungus, *E. tinctorium*, which causes a rust red stringy rot often extending from the roots to above the merchantable top of infected trees. Alone, this fungus caused 45.5 percent of all infections and nearly 71 percent of the total board-foot decay volume. Including mixed infections with *Pholiota* sp., or the fir hydnum, *H. abietis*, the Indian paint fungus was associated with over 48 percent of all decay columns and over 78 percent of the board-foot decay volume. Mixed attacks of *E. tinctorium* and *Pholiota* sp. or *H. abietis* caused more volume loss than single infections by these fungi. Mixed infections by two or more hymenomycete fungi apparently are common in grand and white firs (Hudson 1972, Miller and Partridge 1973, Aho 1976). Hudson (1972) found *H. abietis* associated with 10 of 35 grand firs infected with the Indian paint fungus in a study in Idaho; and Aho (1976) commonly isolated both *H. abietis* and *Pholiota* sp. from *E. tinctorium* decay in white fir in Oregon. Aho (1976) also presented evidence of multiple infections in white firs by *E. tinctorium*. Multiple infections by individual or two or more decay fungi may explain how extensive (roots to tree top) decay columns develop so rapidly in relatively young grand and white firs.

Although *Phellinus* (*Fomes*) *pini* (Thore ex Fr.) Pilát has been reported

to be an important heart rot fungus of balsam firs in other regions, it caused only three infections in this study; but the resultant average decay loss was third highest of all fungi (table 7). *Stereum sanguinolentum* Alb. & Schw. ex Fr. also causes major losses in balsam firs elsewhere and was frequently isolated from grand firs in Idaho (Maloy 1968, Hudson 1972), but it caused only one identified infection in this study.

*Odontia bicolor* (Fr.) Bres. was isolated from decays in grand fir in Idaho (Maloy 1968, Hudson 1972), but was not isolated in this study. *Phellinus* (*Poria*) *weirii* (Murr.) Gilb. and *P.* (*Fomes*) *nigrolimitatus* (Rom.) Bourd, and Galz. were two of the most common fungi associated with root rots in grand fir in Idaho (Miller and Partridge 1973). Extensive *P. weirii* foci were seen adjacent to our plots, but neither *P. weirii* nor *P. nigrolimitatus* were isolated from decay in study trees.

*Impact of E. tinctorium in grand fir.*--The impact of the Indian paint fungus on management and utilization of grand fir in the Blue Mountains cannot be over emphasized. This fungus caused infections in 26 percent of the 1,090 grand fir study trees (table 8). Only four trees less than 100 years of age were decayed by this fungus. This is contrary to Hubert's (1955) report that in Idaho the Indian paint fungus attacks and produces numerous conks on young grand firs. This fungus, however, was not found or only occasionally isolated from trees under 100 years of age by other researchers in Idaho (Maloy 1968, Hudson 1972). In this study, the percentage of trees infected by *E. tinctorium* increased with age from 3 percent in the 50- to 99-year age class to 50 percent or greater in age classes from 250 to 299 years and older (table 8).

Seventy-seven percent of all grand firs infected by the Indian paint fungus had conks. Conkless *E. tinctorium* infected trees were present in every age class. Many infected trees without conks had decay columns which hadn't developed sufficiently to sporulate, or conks had apparently fallen off some trees with very old infections. These types of trees are misread by timber cruisers, causing substantial errors in their net volume estimates.

Total cubic decay volume and the percentage of decay caused by *E. tinctorium* are shown by 50-year age classes in table 8. Decay caused by the Indian paint fungus ranged from a third of the total in trees under 100 to over 73 percent in older age classes.

Table 8--Echinodontium tinctorium *infections and decay volume in grand fir by age classes*

| Age class | Tree basis | *Echinodontium tinctorium* infections | | | | Cubic-foot decay volume | |
|---|---|---|---|---|---|---|---|
| | | Trees | Proportion of trees in age class | With conks | Proportion of *E. tinctorium* infections with conks | Total | Proportion of total caused by *E. tinctorium* |
| | - - Number - - | | Percent | Number | Percent | Cubic feet | Percent |
| 50-99 | 117 | 4 | 3.4 | 1 | 25.0 | 12.6 | 33.3 |
| 100-149 | 316 | 32 | 10.1 | 23 | 71.9 | 377.0 | 76.3 |
| 150-199 | 341 | 111 | 32.6 | 89 | 80.2 | 2,727.4 | 82.1 |
| 200-249 | 206 | 76 | 36.9 | 59 | 77.6 | 2,186.4 | 73.6 |
| 250-299 | 82 | 46 | 56.1 | 38 | 82.6 | 2,557.9 | 76.7 |
| 300-349 | 21 | 12 | 57.1 | 7 | 58.3 | 574.5 | 86.5 |
| 350-399 | 6 | 3 | 50.0 | 2 | 66.7 | 413.6 | 78.3 |
| 450-499 | 1 | 1 | 100.0 | 1 | 100.0 | 82.7 | 100.0 |
| Total or average | 1,090 | 285 | 26.1 | 220 | 77.2 | 8,932.1 | 78.3 |

From these data there can be no doubt of the importance of *E. tinctorium* at least in mature and overmature stands of grand fir in the Blue Mountains.

*Infection courts for fungi.*--The apparent infection courts for fungi attacking grand fir are listed in table 9. Nearly 85 percent of all *E. tinctorium* infections apparently occurred through branches. Some young infections were traced to an individual dead branch or to a whorl of branches. If other injuries were not present, old infections by the Indian paint fungus were assumed to have originated at the branch stub to which the oldest conk was attached. The decay column at that point was usually most advanced in deterioration and size. On this basis many investigators have reported that dead branches and stubs are the primary infection court for *E. tinctorium* (Weir and Hubert 1918, Kimmey 1965, Thomas 1958). Since this study was completed, Etheridge et al. (1972) have determined that the Indian paint fungus infects western hemlock through shade suppressed twigs less than 2 mm in size on living branches. The fungus enters tissues of the pith area of the living main branch through secondary branch traces and remains semiquiescent until conditions arise which promote further growth. Etheridge et al. (1972) speculated that moisture and aeration changes within the branch brought on by branch death or injury promote further growth of the fungus and entrance into the main bole. Preliminary evidence suggests that the Indian paint fungus may infect grand fir in the same manner (Aho and Hutchins 1974).

Nearly 14 percent of the *E. tinctorium* infections were traced to a wide variety of other entrance courts, mainly injuries (table 9). Others have reported that injuries are also infection courts for the Indian paint fungus (Meinecke 1916, Hubert 1955, Boyce 1961). It could be speculated that the injuries may not be the infection site but may promote growth of semiquiescent infections of *E. tinctorium* which are already present (Etheridge et al., 1972) in the tree. Other fungi may invade the injuries resulting in decay columns caused by two or more hymenomycetes. Additional research is needed to resolve this important step in the infection process by *E. tinctorium*.

*Pholiota* sp. was responsible for the second highest number of infections (table 9). Most infections (66.7%) by *Pholiota* sp. occurred through basal wounds.

The fir hydnum, *H. abietis* caused 35 infections, mainly entering through wounds (table 9). Hudson (1972) did not consider this fungus to be a primary invader of grand fir heartwood. He found it mainly associated with *E. tinctorium* decay columns in older trees and was unable to locate its entry courts. Maloy (1968) isolated *H. abietis* from wounds in young grand firs. Aho (1976) found the fir hydnum as a primary invader of white fir (its infection courts were much the same as in table 9) and also as a common associate of *E. tinctorium* and other decay columns.

*Fomitopsis annosa* was responsible for 30 infections, mainly entering trees through roots (table 9). Root rot pockets caused by *F. annosa* occurred on some plots, however, infected trees were not killed. Although commonly a root and butt rot, this fungus also infected trees through dead and broken tops.

Other identified fungi caused relatively few infections in study trees. Unidentified fungi were associated with every type of infection court, but the most important were basal and trunk injuries.

The relative importance of apparent infection courts in grand fir in terms of number of infections and associated decay volumes is shown in table 10.

Table 9--*Apparent infection courts for fungi attacking grand fir*

| Fungus | Apparent infection court | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Branches | Roots | Basal injuries | Trunk injuries | Frost cracks | Forks | Crooks | Crooks and dead vertical branches | Dead vertical branches | Broken tops | Dead tops | Unknown | Total |
| | Percent | | | | | | | | | | | | Number |
| **White trunk rots:** | | | | | | | | | | | | | |
| *Echinodontium tinctorium* | 84.8 | 0.0 | 4.4 | 3.7 | 2.2 | 0.0 | 0.7 | 0.4 | 0.4 | 0.7 | 1.2 | 1.5 | 270 |
| *Pholiota* sp. | 0.0 | 5.2 | 64.8 | 8.8 | 8.8 | 1.8 | 1.8 | 1.8 | 3.5 | 3.5 | 0.0 | 0.0 | 57 |
| *Hericium abietis* | 11.3 | 5.6 | 25.7 | 17.2 | 22.9 | 2.9 | 8.6 | 2.9 | 0.0 | 0.0 | 2.9 | 0.0 | 35 |
| *Phellinus pini* | 66.7 | 0.0 | 33.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 |
| *Amylostereum chailletii* | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 50.0 | 0.0 | 2 |
| *Hirschioporus abietinus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 1 |
| *Stereum sanguinolentum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 1 |
| **White root and butt rots:** | | | | | | | | | | | | | |
| *Fomitopsis annosa* | 0.0 | 70.0 | 6.7 | 3.3 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.7 | 3.3 | 0.0 | 30 |
| *Polyporus tomentosus* var. *circinatus* | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2 |
| *Armillariella mellea* | 0.0 | 66.7 | 33.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 |
| *Corticium galactinum* | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1 |
| **Brown trunk rots:** | | | | | | | | | | | | | |
| *Coniophora puteana* | 0.0 | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 50.0 | 0.0 | 2 |
| *Trechispora raduloides* | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1 |
| *Fomitopsis pinicola* | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1 |
| Unidentified | 1.2 | 11.3 | 39.3 | 17.2 | 8.3 | 0.6 | 3.0 | 0.6 | 3.6 | 9.5 | 5.4 | 0.0 | 168 |
| Total infections[1/] | 41.1 | 8.7 | 22.7 | 9.0 | 6.2 | 0.5 | 1.9 | 0.7 | 1.6 | 4.0 | 2.9 | 0.7 | 577 |

[1/] Does not include entrance courts for 17 mixed fungal infections.

Table 10--*Relative importance of apparent infection courts for fungi attacking grand fir*

| Infection court | Total | Infected | Proportion of total infections 1/ | Amount of decay per infection court | | Proportion of total decay | |
|---|---|---|---|---|---|---|---|
| | | | | Cubic feet | Board feet | Cubic feet | Board feet |
| | Number | Percent | Percent | - - Average - - | | - - Percent - - | |
| Branches | 250 | -- | 42.1 | 24.1 | 376 | 67.5 | 67.5 |
| Roots | 50 | -- | 8.4 | 1.0 | 31 | .6 | .8 |
| Basal injuries | 180 | 73.8 | 22.4 | 6.6 | 103 | 13.3 | 13.7 |
| Trunk injuries | 145 | 36.6 | 8.9 | 4.3 | 75 | 7.0 | 6.6 |
| Frost cracks | 615 | 5.9 | 6.1 | .5 | 8 | 3.4 | 4.0 |
| Forks | 27 | 14.8 | .7 | 3.2 | 47 | 1.0 | 1.0 |
| Crooks | 72 | 15.3 | 1.8 | 1.1 | 17 | .9 | .8 |
| Crooks and dead vertical branches | 15 | 26.7 | .7 | 3.0 | 40 | .5 | .4 |
| Dead vertical branches | 46 | 19.6 | 1.4 | 1.1 | 22 | .6 | .8 |
| Broken tops | 54 | 42.6 | 3.9 | 1.5 | 22 | .9 | .6 |
| Dead tops | 29 | 58.6 | 2.9 | 3.4 | 52 | 1.1 | .7 |
| Unknown | 4 | 100.0 | .7 | 70.7 | 849 | 3.2 | 3.1 |

1/ Includes apparent infection courts for 17 mixed fungal infections.

More than 42 percent of all infections apparently occurred through branches. These infections accounted for nearly 68 percent of the total cubic- and board-foot decay volumes. This probably is a reflection of the importance of *E. tinctorium* in causing decay in mature and overmature grand firs.

Basal injuries, especially old fire scars, were the second most important infection courts. Nearly 74 percent of 180 basal wounds were infected, and they accounted for more than 22 percent of all infections and nearly 14 percent of the board-foot decay volume in study trees. Trunk wounds were next in importance. More than 36 percent of 145 trunk injuries were infected resulting in a volume loss of 75 board-feet per infection. In the future, basal and trunk wounds will probably be the most important infection courts in young, intensively managed grand fir stands. Wound-invading fungi, such as *Pholiota* sp. or *H. abietis* may replace *E. tinctorium* as the most important heart rot fungus in grand fir.

Frost cracks have not been considered to be important infection courts for decay fungi in grand or white firs (Maloy and Gross 1963, Hudson 1972, Aho 1976). In this study, less than 6 percent of 615 frost cracks were infected and associated decay losses were small (table 10). Frost cracks were especially prevalent at the base of trees infected by *E. tinctorium*.

Nearly 59 and 43 percent of dead and broken tops, respectively, were infected by decay fungi. Aho (1976) found these injuries, especially dead tops, to be excellent infection courts in white fir. A high incidence of decay was found associated with dead tops in balsam fir (Stillwell 1956) and in red and white firs in California (Kimmey 1950). Wickman and Scharpf (1972), found little decay associated with white fir tops killed by the Douglas-fir tussock moth in California.

Crooks and dead vertical branches were infrequently infected; and when they were, associated decay volumes were relatively small (table 10). When crooks and dead vertical branches occurred together, both number of infections and average decay volumes were considerably higher than for either infection court alone.

## Conclusions

Grand fir is the most defective of the major commercial species comprising the associated species or mixed conifer types in the Blue Mountains. Nearly 40 percent of the merchantable board-foot volume of grand fir study trees was culled. Grand fir defect loss (percentage of total volume) was more than three times greater than that in Douglas-fir, western larch, or Engelmann spruce. It was not unusual for defect in some grand fir stands to range from 65 to as much as 85 percent. Removal of the highly defective trees is essential so these sites can be put back into maximum production.

Decay in grand fir was found to increase with increasing tree age and diameter. There was so much variation in decay within trees in various age and diameter classes that broad defect factors based on these variables alone are not recommended.

Pathological rotation age in clearcut management, in most localities, should not exceed 150 years otherwise decay losses may be unacceptable. Rotation age based on other considerations will probably seldom exceed 125 years in grand fir. Even in multiple (selection) cut management, it should be possible to hold defect in stands to low levels provided that leave trees are not wounded and that conked and injured trees are removed in intermediate cuts.

It is necessary to inject a word of warning here. Recent studies (in western hemlock and grand fir) have indicated that suppressed grand fir regeneration may be infected with dormant infections by *E. tinctorium* and other decay fungi. If suppressed trees 50 to 75 years old with many dormant infections are released to form new stands, these trees may be very defective at harvest age.

It is not known to what extent trees are infected or whether these infections will cause decay after the regeneration is released. The conditions causing continued growth of the semiquiescent infections are also not known. Death of infected branches or other injuries have been suggested as triggering continued growth in western hemlock (Etheridge et al. 1972). Studies are underway to determine the extent of this potential future decay problem.

Although 14 fungi were identified as causing decay in grand fir in this study, only four caused more than three infections or significant cull losses. They were *E. tinctorium*, *Pholiota* sp., *H. abietis*, and *F. annosa*. Of these, *E. tinctorium*, was of major importance. The Indian paint fungus was associated with more than 48 percent of all infections which accounted for almost 80 percent of the total board-foot decay volume in grand fir. Nearly 85 percent of the infections caused by this fungus apparently originated through branches.

*Pholiota* sp. and *H. abietis* attacked trees through injuries; the most important being basal and trunk wounds. Although *E. tinctorium* is without a doubt the major decay fungus in old-growth grand fir stands, *Pholiota* sp. or *H. abietis* may become more important in young, intensively managed stands. Wounding of residual trees during thinning and selection harvest operations must be held to a minimum. Of course, the Indian paint fungus may be a significant factor in stands formed from advanced reproduction.

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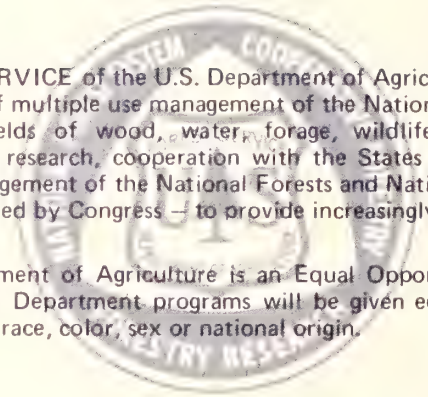

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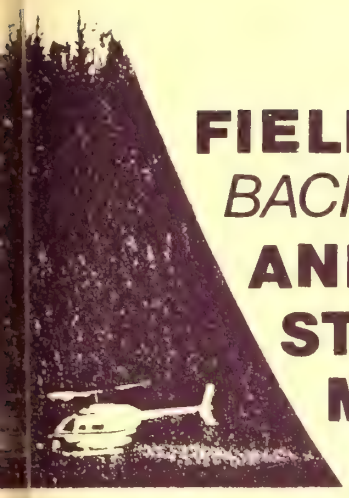

# FIELD TESTS OF *BACILLUS THURINGIENSIS* AND AERIAL APPLICATION STRATEGIES ON WESTERN MOUNTAINOUS TERRAIN

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The research reported here was funded in whole or part by the USDA Expanded Douglas-fir Tussock Moth Research & Development Program. This paper reports the results of research only. Mention of a pesticide does not constitute a recommendation for use by the USDA, nor does it imply registration under FIFRA as amended, also mention of a proprietary product does not constitute an endorsement by the USDA.

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# *FIELD TESTS OF* BACILLUS THURINGIENSIS *AND AERIAL APPLICATION STRATEGIES ON WESTERN MOUNTAINOUS TERRAIN*

## Reference Abstract

Thompson, C. G., John Neisess, and Harold O. Batzer.
1977. Field tests of *Bacillus thuringiensis* and aerial application strategies on western mountainous terrain. USDA For. Serv. Res. Pap. PNW-230, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Aerial applications of *Bacillus thuringiensis* products were used to compare five formulations, three rates of application, and two spray droplet spectra. A formulation including a sunscreen was superior to the others tested, and the coarser spray atomization provided better spray coverage and residual activity.

KEYWORDS: Pesticide preparations, bioassay, virus (-forest pest control, *Bacillus thuringiensis*, Douglas-fir tussock moth, *Orgyia pseudotsugata*, western spruce budworm, *Choristoneura occidentalis*.

## RESEARCH SUMMARY

Research Paper PNW-230
1977

The effectiveness of aerial applications of five tank mixes of Dipel WP® and four Thuricide® treatments applied with different droplet spectra and application rates were evaluated against *Choristoneura occidentalis* Freeman and *Orgyia pseudotsugata* (McDunnough). Of the various tank mixes, the formulation of 25% Sorbo® and 0.5 lb/gal Shade® provided the best foliage protection and protected the viable *Bacillus thuringiensis* (Berliner) spores and prevented loss of insecticidal activity for at least 3 days. The coarser atomizations (> 300 µm vmd) produced superior spray coverage; the residual insecticidal activity lasted for 3 days posttreatment. The fine atomization (about 150 µm) started to degrade immediately.

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## Introduction

Commercial preparations of *Bacillus thuringiensis* Berliner *(B.t.)* are available from several manufacturers. These microbial insecticides have been very effective against some insect pests of agricultural crops where applications by ground equipment or by low-flying aircraft insure thorough coverage of the crop. Aerial applications of the same formulations and products against forest insects in mountainous terrain have often given erratic results (for example, Maksymiuk et al.,[1/] Maksymiuk and Neisess 1975, Stelzer et al. 1975, Stelzer and Neisess,[2/] Angus and Luthy 1971). The tests reported here were an effort to determine spray formulation and application characteristics needed for reliable forest defoliator control. Field populations of the western spruce budworm, *Choristoneura occidentalis* Freeman, and laboratory cultures of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), were used to measure insecticidal efficacy.

The variables tested were: application rate, droplet size, and effects of various spray adjuvants. Tests of application rate and droplet size were 0.5, 1.0, and 2.0 gallons per acre (4.67, 9.35, and 18.70 liters per hectare) and attempted droplet sizes of 150- and 300-um volume median diameters (vmd).[3/] Actual droplet size varied with spray formulation and atmospheric conditions. Dipel WP® was used for the spray adjuvant studies because it is a relatively simple product. Thuricide® was used for the studies on application rates and droplet sizes because it can be applied in lower volumes than the Dipel WP.

## Materials and Methods

Dipel WP ($16 \times 10^3$ international units/mg), a commercial wettable powder formulation of *B. thuringiensis*, was applied in five different tank mixes at the rate of 1 lb Dipel/2 gal per acre, which is equivalent to 7.264 billion international units of potency per acre (BIU/acre). Tank mixes are listed in table 1.

To evaluate the application parameters--droplet size and application rate--four Thuricide mixtures were applied as follows: 8 BIU of Thuricide 16B/gal per acre (8 BIU/9.35 liters per hectare) with coarse spray atomization; 8 BIU of Thuricide 16B/gal per acre (8 BIU/9.35 liters per hectare) with fine atomization; 8 BIU of Thuricide 24B/0.5 gal per acre (8 BIU/4.675 liters per hectare) with fine atomization; 8 BIU of Thuricide 32B/2 gal per acre (8 BIU/18.7 liters per hectare) with fine atomization. The 2-gal/acre (18.7 liters/acre) treatment was formulated in a 25% Sorbo® solution in water. The other treatments were formulated in water (table 1).

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[1/] Maksymiuk, Bohdan, P. A. Boving, R. D. Orchard, and R. G. Winterfeld. 1968. Forest tests to develop an operational method to control the Douglas-fir tussock moth with a polyhedrosis virus. Progress report, USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Forestry Sciences Laboratory, Corvallis, Oregon, and Agric. Eng. Res. Division, Forest Grove, Oregon. 33 p.

[2/] M. J. Stelzer and J. A. Neisess. 1974. 1975 Field experiments with *Bacillus thuringiensis* to control Douglas-fir tussock moth in Idaho. Study No. 3. Douglas-fir tussock moth research and pilot test program, season of 1974. Interim report, USDA For. Serv., Pac. Northwest For. and Range Exp. Stn. 9 p.

[3/] Volume median diameter (vmd) is the drop diameter satisfying the requirement that half of the volume of spray is in drops smaller and half in drops larger than the vmd.

Table 1 --*Summary of treatments and application parameters, Ellensburg, Washington, 1975*

| Test parameter | Active ingredient | Tank mix | Application rate | Proposed atomization |
|---|---|---|---|---|
| | BIU[a]/acre | | Gal/acre[b] | Micrometers |
| Formulations | 7.264 BIU Dipel WP | $H_2O$ + 0.125% BioFilm[c] | 2 | 300 |
| | 7.264 BIU Dipel WP | $H_2O$ + 25% CIB molasses | 2 | 300 |
| | 7.264 BIU Dipel WP | $H_2O$ + 25% Sorbo[d] | 2 | 300 |
| | 7.264 BIU Dipel WP | $H_2O$ + 25% Sorbo + 0.5 lb/gal shade[e] | 2 | 300 |
| | 7.264 BIU Dipel WP | $H_2O$ + 25% Sorbo + 0.1% AL 411F sticker[f] | 2 | 300 |
| Application parameters | 8 BIU Thuricide 16B | 50:50 with $H_2O$ | 1 | 300 |
| | 8 BIU Thuricide 16B | 50:50 with $H_2O$ | 1 | 150 |
| | 8 BIU Thuricide 24B | 67:33 with $H_2O$ | 0.5 | 150 |
| | 8 BIU Thuricide 32B | 25% Sorbo + 50% $H_2O$ + 25% Thuricide 32B | 2 | 150 |
| | Untreated control | | | |

[a] BIU - billion ($10^9$) international units.

[b] One gallon per acre equals 9.35 liters per hectare.

[c] Colloidal Products Corp., Petaluma, Calif.

[d] A 70% Sorbitol solution which is a polyhydric alcohol derived from D-glucose, ICI United States, Inc., Wilmington, Del.

[e] Sandoz, Inc., Homestead, Fla., 0.5 lb/gal = 0.0599 kg/l.

[f] ICI United States, Inc., Wilmington, Del.

Rhodamine B Extra S[4] was added to each tank mix at the rate of 3.785 g/gal (1 g/liter) for spray-deposit assessment. Tank samples were collected for each replicate of every treatment for the determination of dye and *B. thuringiensis* concentrations.

## EXPERIMENTAL LAYOUT

The study was conducted on thirty 15-acre (6.075 hectares) plots that were established in stands of Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and grand fir, *Abies grandis* (Dougl.) Lindl., infested with spruce budworm in the Wenatchee National Forest north of Ellensburg, Washington. Near the center of each plot, 15 trees were designated for population, residue, and spray-deposit sampling. Sample trees were Douglas-fir or grand fir, 30 to 50 feet (9.144 to 15.240 meters) tall, open-grown, and not shielded by larger trees. Because all plots were within one continuous area, the same checks were used for each part of the field experiment. The treatments were assigned to the plots at random to give a completely random design of three replicates of each treatment.

A Hiller 12-E helicopter equipped with either conventional spray boom and flat fan nozzles or a Bals Turbair Spinning Disk spray system was used to apply all materials. The boom and nozzles, fitted with Spraying Systems (Wheaton, Ill.) T8002 flat fan tips, were used to apply the coarse atomization treatments. The nozzles were oriented forward and down 45° to the line of flight of the helicopter. The ambient boom pressure was 60/lb

[4] General Aniline Film Corp., Portland, Oregon.

per $in^2$ (4.218 kg/cm). The spinners were calibrated to spin at 9,361 revolutions per minute (rpm) without any liquid flowing. The spinning speed was reduced to about 9,000 rpm when the spray was applied. The helicopter sprayed at 45 mph (72.42 km/h) at about 50 ft (15.240 m) above the trees. Swath spacings ranged between 50 and 100 ft (15.240 and 30.48 m) depending on the application rate and desired flow rate of each treatment.

Plots were sprayed when 70% of the budworm population had reached the fourth larval instar.

## EVALUATION

Measurements of the density of western spruce budworm populations were made 1 to 2 days before treatment and 1, 2, 3, 5, 7, and 14 days after treatment and at pupation.

At each sampling interval, four 15-inch (38.1-cm) branches with a minimum of 50 shoots were collected from the midcrown of each sample tree. In the field laboratory, the current year's shoots were counted, as well as the number of budworm larvae per branch. Population estimates were expressed as budworms per 100 new shoots. At each sampling interval, up to 10 larvae were collected from foliage samples from each sample tree and placed in individual disposable petri dishes containing an artifical diet (McMorran 1965). These dishes were held in the laboratory at 25°C and 40-50% relative humidity (RH) for 14 days; then the dead larvae were examined microscopically to diagnose the cause of death (that is, bacterial infection, parasitism, or unknown).

Spray deposit was sampled on the ground with aluminum plates and white Kromekote® cards. Volume median diameter (vmd) of droplets and densities of droplets on the Kromekote cards were measured with a Quantimet® 720 particle analyzer. Spray deposits were removed from the aluminum plates with 10 ml of distilled water, and amount of spray deposit was determined by fluorometric analysis (Maksymiuk et al. 1975). Deposit values were expressed as gallons per acre. Spray residues were determined from the same midcrown branches used for spruce budworm counts. Foliage was collected from every sample tree immediately postspray (about 30 minutes), and at 1, 2, 3, 5, and 7 days postspray. Samples were divided into two subsamples, one for fluorometric analysis and one for bioassay.

After the foliage samples had been dried, 5-g and 200-needle subsamples were selected from each foliage sample. Spray residues were removed from the 5-g samples by washing with 50 ml of distilled water. Spray deposit, in terms of concentration of fluorescent dye, was measured with a Model 430 Turner Spectrofluorometer. The volume of spray per gram of foliage was determined from the amount of dye removed from the needles and the dye concentrations in the tank samples. The 200-needle samples were weighed, and the number of spray droplets were counted using a dissecting microscope with an ultraviolet light for illumination of the fluorescent deposit. The counts were expressed in terms of droplets per 100 needles and percentage of needles that had at least one spray droplet.

The foliage samples designated for bioassay were dried, and 5 g of needles from each tree were placed in 4-oz (29.57-ml) plastic cups. Fifty ml of distilled water was pipeted into each cup, and the cup was agitated for about 2 min on a Maxi Mix® model M-16715 stirrer. One drop (0.025 ml) of each wash suspension was spread on the surface of artificial medium in a 1/2- by 2-inch (1.27- by 5.08-cm) clear polystyrene vial. Individual neonatal Douglas-fir tussock moth larvae from our laboratory colony were placed on the treated diet, and the vials were sealed with Parafilm®. Mortalities

were recorded after the larvae were held at 26°C and 45% RH for 14 days. Three replicates (10 larvae/replicate, 1 foliage sample/rep per treatment) were tested for each treatment and sample interval. Control groups of 30 larvae, exposed to untreated diet, were set up for each 150 sample vials.

Three-ml portions of the wash solution from each of the immediate postspray samples were placed in 1/2- by 2-in (1.27- by 5.08-cm) vials and pasteurized for 15 minutes in an 80°C water bath. The wash suspensions were plated on nutrient agar by standard bacteriological techniques. Developing colonies were spot checked for *B.t.* endospores. Viable spore counts were expressed as spores per gram of foliage.

Defoliation estimates were made on the final foliage samples based on the average new foliage loss on each shoot, by a method similar to that described by Heller and Schmiege (1962).

### ANALYSIS

Spruce budworm survival, initial infection rate, Douglas-fir tussock moth mortality from the bioassay of foliage samples collected immediately postspray, viable *B.t.* spore counts, and deposit data were subjected to analysis of variance. Data pertaining to the two studies, formulation and application variables, and for different sampling intervals, were analyzed separately. Defoliation data was subjected to analysis of covariance using the prespray density of spruce budworms as the covariate. In each analysis of variance or covariance, the sum of squares among treatments was partitioned into sets of orthogonal single degree-of-freedom comparisons to test differences in treatment parameters. Data from bioassay of Douglas-fir tussock moth and rate of spruce budworm infection for all the sampling intervals were analyzed by analysis of variance with time (sampling intervals) as a split plot factor.

## *Results and Discussion*

### FORMULATIONS

Although the five different Dipel tank mixes were applied under the same application parameters, different droplet size spectra existed with the Dipel-BioFilm® tank mix having the smallest vmd (table 2). Table 3 summarizes the single degree-of-freedom contrasts that evaluate and compare the various spray adjuvants. The addition of the sticker to the Sorbo mixture increased the viscosity of the solution enough to increase the atomization significantly. Although the vmd for the BioFilm tank mix was significantly ($p \leq 0.01$) lower than the molasses treatment, this finer atomization did not result in significantly higher droplet densities or spray volumes either at the ground or midcrown. Deposit results for BioFilm and molasses are consistent with those found by Stelzer et al. (1975), who attributed the lower deposit of the BioFilm tank mix to the higher evaporation rate. Besides droplet size, atomization-dependent deposit variables, such as drops per needle, varied for some treatments (table 2).

Fluorometric analysis of the Sorbo + Shade® treatment gave erroneous results for gallon per acre and microliters of spray per gram of foliage. We found in later laboratory experiments that fluorescent intensity of the Sorbo + Shade + dye solution declined over time. Tank samples were stored about 3 to 4 months before analysis, so the analyzed dye concentrations were 4 to 5 times lower than the concentrations of dye actually added to the tank mixes. Because the dried deposits did not fade (on the plates and foliage), the deposit values analyzed 4 to 5 times higher than the real values.

Table 2 --*Deposit data for 1 lb Dipel WP/2 gal per acre (7.26 BIU/acre) mixed with various spray adjuvants, Ellensburg, Washington*

| Formulation | Vmd | Droplets/cm$^2$ | Droplets/needle | Droplets with needles | Amount recovered | Spray/ foliage |
|---|---|---|---|---|---|---|
| | Micrometers | Number | | Percent | Gal/acre | µl/g |
| 0.125% BioFilm | 192 | 13.0 | 1.614 | 51.6 | 0.642 | 0.074 |
| 25% CIB molasses | 355 | 16.0 | 1.130 | 48.3 | 0.857 | 0.223 |
| 25% Sorbo | 274 | 7.7 | 0.421 | 26.5 | 0.294 | 0.128 |
| 25% Sorbo + 0.5 lb Shade/gal | 289 | 11.7 | 0.282 | 12.5 | 3.209[a/] | 0.976[a/] |
| 25% Sorbo + AL 411F Sticker | 363 | 13.0 | 0.968 | 47.2 | 0.542 | 0.115 |

a/ Fluorometric analysis was inhibited by Shade adjuvant. Table values are 4-5 times higher than actual volumes.

Table 3 --*Summary of F values for single degree of freedom comparisons of the effect of Dipel WP formulations mixed with various spray adjuvants on deposit parameters*

| Contrast | Vmd | Droplets/cm$^2$ | Droplets/needle | Needles with droplets | Amount recovered | Spray/ foliage |
|---|---|---|---|---|---|---|
| Sorbo vs. non-Sorbo formulations | 4.330 NS | 1.067 NS | 5.898 * | 7.128 * | -- | -- |
| Molasses vs. BioFilm | 39.215 ** | 0.289 NS | 0.869 NS | 0.070 NS | 0.400 NS | 3.164 * |
| Sorbo vs. Sorbo with additives | 5.309 * | 0.932 NS | 0.206 NS | 0.101 NS | -- | -- |
| Sorbo + Sticker vs. Sorbo + Shade | 8.043 * | 0.057 NS | 1.743 NS | 7.918 * | -- | -- |

* = significant at 0.05 level, 1 and 10 df.

** = significant at 0.01 level, 1 and 10 df.

NS = nonsignificant.

Survival ratios of western spruce budworms did not differ for any of the treatments until the 14-day sample. Then the mean survival ratio for all Dipel tank mixes was significantly lower than the control (table 4). Apparently the 60% increase in initial infection rate (table 4) achieved with the molasses treatment compared to the BioFilm treatment was not great enough to cause differences in the survival ratio measured in the field. No other differences in the infection rate were significant (table 5). The survival data (table 4) corroborate the defoliation data where all the Dipel mixtures provided significantly ($p \leq 0.05$) better foliage protection than the control. Although the survival ratio for the Sorbo + Shade treatment was not significantly different from the other Sorbo treatments, the effect of the reduced survival rate for this treatment was observed in the defoliation data. Foliage protection provided by the Sorbo + Shade treatment was significantly greater than the protection

Table 4 --*Biological responses to 0.5 lb Dipel WP/gal mixed with various spray adjuvants, Ellensburg, Washington*

| Treatments: Dipel WP + | Prespray budworm population (larvae/ 100 shoots) | Spruce budworm survival ratio | | | Defoliation rate | Infection rate in budworm | 0-day viable *B.t.* spore/g foliage x $10^3$ a/ | 0-day DFTM mortality |
|---|---|---|---|---|---|---|---|---|
| | | 5-day | 7-day | 14-day | | | | |
| | | | | | | Percent | | Percent |
| 0.125% BioFilm | 18.0 | 1.203 | 1.203 | 0.873 | 0.556 | 25.3 | 50.7 | 53.9 |
| 25% molasses | 25.3 | 1.020 | 0.987 | 0.693 | 0.490 | 40.7 | 79.3 | 77.0 |
| 25% Sorbo | 24.7 | 0.917 | 0.773 | 0.723 | 0.586 | 35.3 | 96.0 | 56.1 |
| 25% Sorbo + 0.5 lb Shade/gal | 29.6 | 0.897 | 0.747 | 0.390 | 0.394 | 47.0 | 206.0 | 58.9 |
| 25% Sorbo + AL 411F Sticker | 30.6 | 0.960 | 1.137 | 0.633 | 0.637 | 39.3 | 214.0 | 77.8 |
| Untreated control | 30.7 | 0.890 | 1.220 | 1.217 | 0.713 | 0.0 | 0.0 | 19.1 |

a/ Samples collected 30 minutes postspray.

Table 5 --*Summary of F values for individual degree of freedom comparisons of means in analysis of variance of spruce budworm survival and infection data, Douglas-fir tussock moth mortalities, viable spore counts, and defoliation data*

| Contrast 1 and 12 df | F values | | | | | | |
|---|---|---|---|---|---|---|---|
| | Spruce budworm survival ratio | | | Defoliation rate | Infection rate | Viable spores/ g foliage | 0-day DFTM mortality |
| | 5-day | 7-day | 14-day | | | | |
| All treatments vs. control | 0.853 NS | 2.329 NS | 6.544 * | 5.110 * | — | -- | 44.358 ** |
| Sorbo vs. non-Sorbo. (1+2 vs. 3+4+5) | 3.604 NS | 2.341 NS | 1.242 NS | 0.056 NS | 3.773 NS | 7.089 * | 0.205 NS |
| Molasses vs. BioFilm | 1.440 NS | 1.044 NS | 0.415 NS | 0.397 NS | 6.475 * | 0.211 NS | 7.827 * |
| Sorbo vs. Sorbo with additives | 0.008 NS | 0.840 NS | 0.764 NS | 0.628 NS | 2.253 NS | 4.467 * | 3.606 NS |
| Sorbo + Sticker vs. Sorbo + Shade | 0.172 NS | 3.381 NS | 0.758 NS | 5.760 * | 1.619 NS | 0.017 NS | 4.982 * |

* = significant at 0.05 level, 1 and 10 df.

** = significant at 0.01 level, 1 and 10 df.

NS = nonsignificant.

provided by the Sorbo + sticker.

All of the Dipel mixtures had significantly higher initial Douglas-fir tussock moth bioassay mortalities than the control (tables 4 and 5). The formulation with molasses gave significantly higher ($p \leq 0.05$) mortalities than the one with BioFilm. Likewise, the addition of the sticker to the Sorbo mixture significantl ($p \leq 0.05$) increased the bioassay mortalities. The increased mortality of the Sorbo + sticker treatment can be partiall explained by the increased deposit (table 2 and 3), especially the percentage of needles with spray drops. Because the deposits for the molasses treatments were not significantly higher than the BioFilm treatment (tables 2 and 3), some other

factor must explain the higher bioassay mortalities. Molasses could be acting as a gustatory stimulant. Yendol et al. (1975) reported such a stimulant with gypsy moth, *Lymantria dispar* (L.), fed commercial *B.t.* preparations. The addition of Shade and sticker to the Sorbo mixture apparently protected the viable spores from degradation, even while the spray droplets were airborne (table 4), because the number of viable spores for these two treatments were significantly higher (table 5) than the Sorbo-only treatment. If the adjuvants protected the spray droplets only after they were deposited on the foliage, the viable spore counts from the initial postspray sample should have been about equal, and significant differences in spore counts would only show up in the subsequent daily residue samples.

Analysis of variance of the residual activity data (Douglas-fir tussock moth bioassay and spruce budworm infection rate for the various sampling intervals) where time was a factor showed significant treatment by time interactions ($F = 1.74$ with 36 and 80 df and $F = 6.492$ with 40 and 90 df, respectively). This significant interaction indicated that various treatments responded differently over time. Figure 1 shows a plot of bioassay mortality against time for two such treatments, Sorbo and Sorbo + Shade. The addition of Shade obviously affected the residual activity of the *B.t.* The activity of the Sorbo treatment steadily declined from the initial postspray sample, but the activity of the Sorbo + Shade treatment remained at virtually 100% until after the 3-day sample. Plots of the spruce budworm infection data showed the same trend, except the activity of the Sorbo + Shade treatment

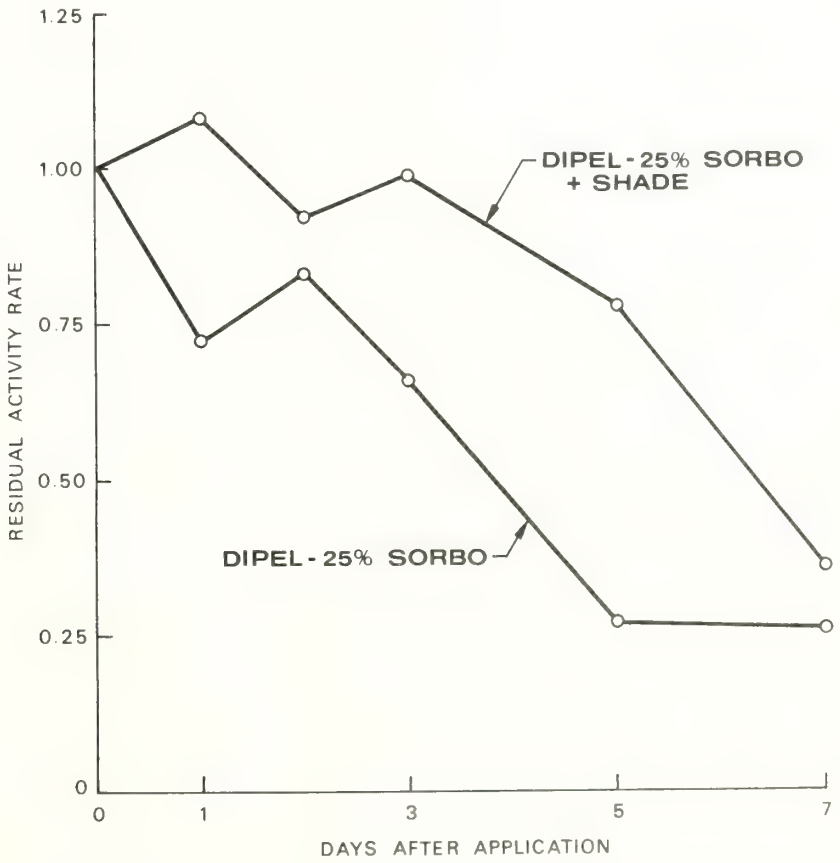


*Figure 1.--Residual activity of* Bacillus thuringiensis *formulated with and without a sunscreen.*

remained at 100% for about 5 days. These differences in residual activity result from addition of Shade to the mixture, because initial mortality and deposit values were equivalent for these two treatments.

## DROPLET SIZE AND APPLICATION RATE

Although the fine droplet spectra (164-µm) resulted in significantly more droplets per $cm^2$, the coarse atomization (411-µm) allowed significantly greater volumes of spray to reach the midcrown and ground levels (tables 6 and 7). Although enough variations existed in the values for droplets per needle and percentage of needles with droplets that observed differences could not be concluded as real differences, coverage for the coarser atomization of this experiment would have to be judged superior to that of the fine droplet spectra. This is so because coverage is a compromise between volume and number (droplets/area). At first glance, the practical significance of these differences in deposit are questionable because tables 7 and 8 show that defoliation was the only biological response with a significant difference ($p \leq 0.05$). We found no significant differences between the two droplet sizes in spruce budworm survival, initial mortality in the Douglas-fir tussock moth bioassay, viable spore counts, or rate of spruce budworm infection. This was because of the biological variability encountered in these tests. Analysis of variance of the residual activity data, when time

Table 6 --*Deposit data resulting from changes in application parameters-- droplet size and application rate*

| Treatment | Application rate | Vmd | Droplets/$cm^2$ | Droplets/needle | Needles with droplets | Amount recovered | Spray/foliage |
|---|---|---|---|---|---|---|---|
| | (Gal/acre) | (Micrometers) | - - - - Number - - - - | | Percent | Gal/acre | µl/g |
| Thuricide 16B | 1.0 | 411 | 7.3 | 0.925 | 43.1 | 1.177 | 0.316 |
| Thuricide 16B | 1.0 | 164 | 16.7 | 0.422 | 23.8 | 0.144 | 0.018 |
| Thuricide 24B | 0.5 | 172 | 12.3 | 0.123 | 9.6 | 0.085 | 0.042 |
| Thuricide 32B | 2.0 | 220 | 15.7 | 0.733 | 32.9 | 0.229 | 0.070 |

Table 7 --*Summary of F values for single degree of freedom comparisons of means in analysis of variance of spray deposit data for changes in droplet size and application rate of four Thuricide treatments*

| Contrast | Vmd | Droplets/$cm^2$ | Droplets/needle | Needles with droplets | Amount recovered | Spray/foliage |
|---|---|---|---|---|---|---|
| Fine drops vs. coarse (164 vs. 411 vmd) | 68.546 ** | 7.649 * | 2.608 NS | 3.725 NS | 519.618 ** | 20.211 ** |
| 1 gal/acre vs. ½ + 2 gal | 18.763 ** | 0.702 NS | 1.244 NS | 2.967 NS | 246.728 ** | 5.591 * |
| ½ gal/acre vs. 2 gal/acre | 2.546 NS | 0.976 NS | 3.835 NS | 5.426 * | 10.151 * | 0.174 NS |

* = significant at 0.05 level, 1 and 10 df.
** = significant at 0.01 level, 1 and 10 df.
NS = nonsignificant.

Table 8 --*Biological response variables for application parameters, droplet size, and application rate*

| Treatment and parameter | Prespray budworm population (larvae/ 100 shoots) | Spruce budworm survival ratio | | | Defoliation rate | 0-day DFTM mortality | Viable spore/ g of foliage x 10³ | Infection rate in budworm |
|---|---|---|---|---|---|---|---|---|
| | | 5-day | 7-day | 14-day | | | | |
| | | | | | | Percent | | Percent |
| Thuricide 16B large drops (411µm) | 27.0 | 0.923 | 1.063 | 0.547 | 0.576 | 46.4 | 355.0 | 42.0 |
| Thuricide 16B small drops (164µm) 1 gal/acre | 33.4 | 0.807 | 0.697 | 0.553 | 0.765 | 46.3 | 132.1 | 47.7 |
| Thuricide 24B 0.5 gal/acre | 25.6 | 0.987 | 0.710 | 0.443 | 0.480 | 68.7 | 268.2 | 29.0 |
| Thuricide 32B 2 gal/acre | 31.3 | 0.583 | 0.497 | 0.387 | 0.626 NS | 50.4 | 73.3 | 51.0 |
| Untreated control | 30.7 | 0.890 | 1.220 | 1.217 | 0.762 NS | 17.0 | 0.0 | 0.0 |

(sample interval) was a factor, however, showed significant differences between treatments. Figure 2 illustrates how the bioassay mortalities varied over time for the two droplet sizes. The initial residual activity of the coarse droplet spectra lasted for 3 days postspray, but the activity of the fine droplets started to degrade immediately. Because the volume of spray in the coarse droplets was significantly greater (tables 6 and 7) than the fine droplets, this result was not unexpected.

Application at 2 gal/acre (18.70 liter/ha) consistently provided the best deposit (table 6), with values for percentage of needles with droplets and gallons per acre significantly higher than at 0.5 gal/acre (4.675 liter/ha). The inconsistent data on droplets per square centimeter for the various treatments may have been because the cards were too close to surrounding trees, which could have screened some of the spray. The only biological responses that paralleled the deposit results were the infection rate (table 8) and the 5-day spruce budworm survival, and these responses did not consistently correlate with the defoliation data. Although the 2-gal/acre (18.70-liter/ha) treatment resulted in a significantly higher initial rate of infection, defoliation resulting from the 2-gal/acre (18.70-liter/ha) treatment appears (difference was not significant, table 9) to be greater than with 0.5 gal/acre (4.675 liter/ha) (table 8). This inconsistency can partly be explained by the difference in density of spruce budworm larvae before spraying. Although analysis of covariance was used to adjust the defoliation rates according to initial larval densities, no prespray defoliation measurements were recorded. The applications were timed against fourth-instar larvae, so considerable defoliation had occurred before treatment--especially in plots with the higher densities--which our analysis could not properly evaluate. Stelzer et al. (1977) observed that with 1- and 2-gal/acre (9.35- and 18.7-liter/ha) applications of baculovirus against Douglas-fir tussock moth, all deposit values from the 2-gal/acre (18.7-liter/ha) application rates were

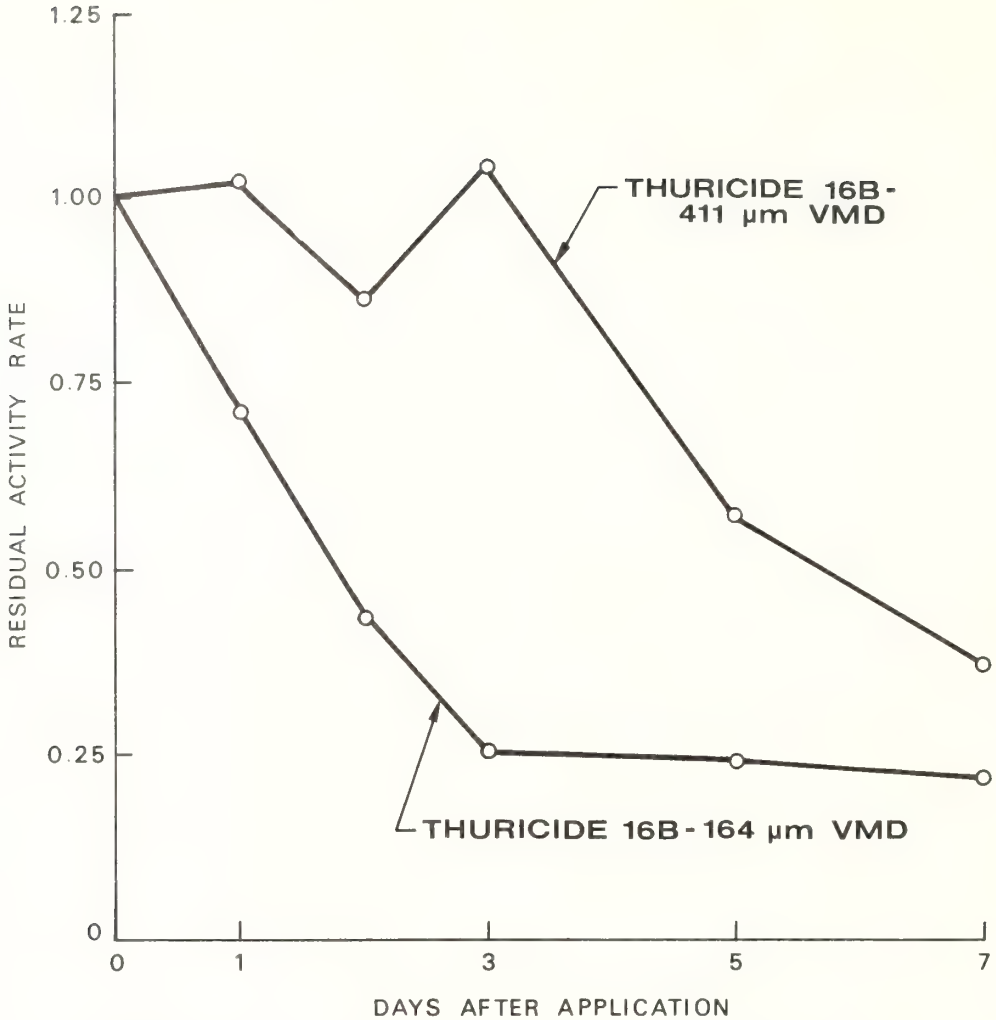


*Figure 2.--Residual activity of* Bacillus thuringiensis *at two droplet ranges.*

Table 9 --*Summary of F values for orthogonal comparisons of means from the analysis of variance of biological response variables for the application parameters droplet size and application volume*

| Contrast | Spruce budworm survival | | | Defoliation rate | 0-day DFTM mortality | Viable spores/ g of foliage | Infection rate |
|---|---|---|---|---|---|---|---|
| | 5-day | 7-day | 14-day | | | | |
| All treatments vs. control | 0.238 NS | 11.207 ** | 14.422 ** | 6.003 * | 15.178 ** | -- | -- |
| Small drop vs. large | 0.480 NS | 4.116 NS | 0.001 NS | 5.6593 * | 0.000 NS | 2.507 NS | 1.151 NS |
| 1 gal/acre vs. ½+2 gal/acre | 0.451 NS | 4.686 NS | 0.610 NS | 4.5927 NS | 2.565 NS | 0.535 NS | 1.675 NS |
| ½ gal/acre vs. 2 gal/acre | 5.733 * | 1.393 NS | 0.054 NS | 3.389 NS | 2.459 NS | 1.918 NS | 17.355 ** |

* = significant at 0.05 level, 1 and 10 df.
** = significant at 0.01 level, 1 and 10 df.
NS = nonsignificant.

about double the 1-gal/acre (9.35-liter/ha) values, but the biological responses were equal. The reason our experiment did not provide such clearcut differences in deposit value might be the small droplet size--around 150-µm. The droplet sizes used in the virus experiment were 200 to 300-µm. Our variable data seem to indicate that the droplet size may have been too fine to yield uniform deposition, which would explain the inconsistent results in our response variables. Also budworms are more numerous in the upper portion of the tree crown, and defoliation in the upper crown may force this portion of the population down into the midcrown. As a result, populations in some test plots increased in our midcrown samples. The average budworm population for one treatment (1 gal/acre (9.35 liter/acre), small droplets) increased from 33 larvae/100 shoots prespray to 45 larvae/100 shoots 3 days after spraying. Because all population reduction figures were based on reduction from prespray counts, they did not always reflect actual conditions.

## EFFECT OF *B.t.* TREATMENTS ON INSECT PARASITISM

In determining causes of mortality in laboratory rearings of budworm samples collected from each plot, we recorded budworm larvae killed by insect parasites. The percentage of parasitism in larvae not killed by *B.t.* in all treated plots was almost identical to that in larvae from the control plots (fig. 3). This finding supports the environmental compatibility of *B.t.* treatments with parasitic insect species. We did find that two of the major parasites observed in our studies (*Glypta fumiferanae* (Viereck) and an *Apantelei* sp.) could acquire lethal *B.t.* infections from their host budworm. Not uncommonly, we observed apparently fully developed parasite larvae emerging from their host only to die before they could pupate. These parasites demonstrated typical symptoms of advanced infection and were always packed with all stages of *B.t.* Almost always, the host budworm larvae remained alive until the parasite larvae had emerged. Few parasites emerged from hosts that had been dead (from *B.t.* infection) for any length of time. Thus, although the *B.t.* treatments appear to have had no effect on adult parasites or those immature parasites in uninfected hosts, these treatments did reduce the number of parasites surviving host infections--even where the host remained alive long enough for the parasite to mature sufficiently to emerge and, sometimes, even spin a cocoon.

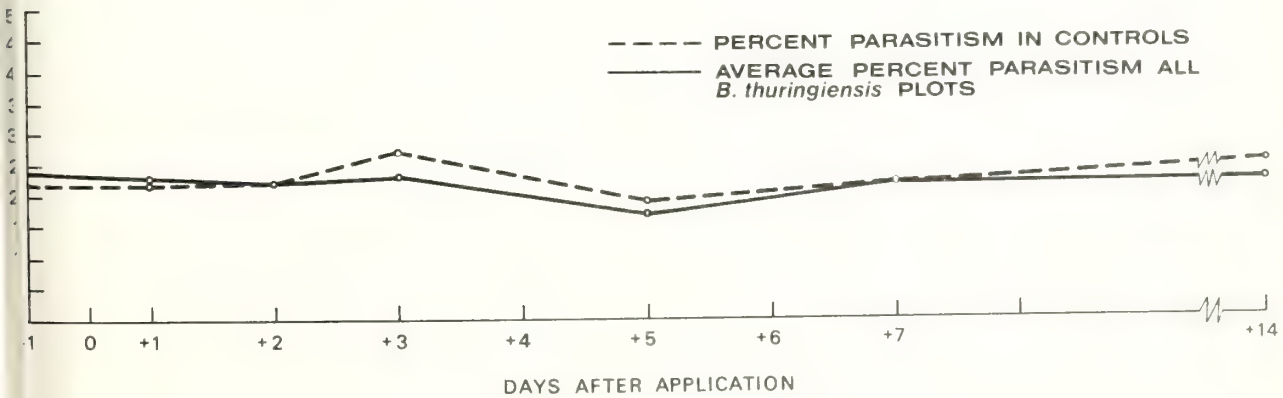


*Figure 3.--Percent parasitism in budworm rearing samples not killed by* B.t.

## Conclusions

Although not all the test objectives were fully realized, the results justify these conclusions:

1. The addition of a sticker to the Sorbo mixture increased viscosity and spray droplet size.

2. The BioFilm mixture produced finer atomization, but this did not result in greater coverage.

3. All treatments significantly reduced budworm populations; but under the test conditions, none of the treatments provided satisfactory population regulation.

4. Foliage protection was greater with the Sorbo and Shade formulation than with the Sorbo and sticker.

5. The addition of Shade to the Sorbo formulation protected viable spores from degradation for 3 days. Insecticidal activity of spray deposit with the Shade formulation was extended to 5 days.

6. The coarser atomizations appeared to produce superior spray coverage. Residual activity of the coarse droplets lasted for 3 days postspray, but the fine droplets started to degrade immediately.

7. Insect parasitism was not affected in the budworm populations that escaped the *B.t.* treatments.

8. Two species of parasites readily acquired *B.t.* from infected host budworms.

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1977. Field tests of *Bacillus thuringiensis* and aerial application strategies on western mountainous terrain. USDA For. Serv. Res. Pap. PNW-230, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Aerial applications of *Bacillus thuringiensis* products were used to compare five formulations, three rates of application, and two spray droplet spectra. A formulation including a sunscreen was superior to the others tested, and the coarser spray atomization provided better spray coverage and residual activity.

KEYWORDS: Pesticide preparations, bioassay, virus (-forest pest control, *Bacillus thuringiensis*, Douglas-fir tussock moth, *Orgyia pseudotsugata*, western spruce budworm, *Choristoneura occidentalis*.

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# An Equation For [ESTIMATING The (VALUE And VOLUME) Of (Western Larch Trees)]

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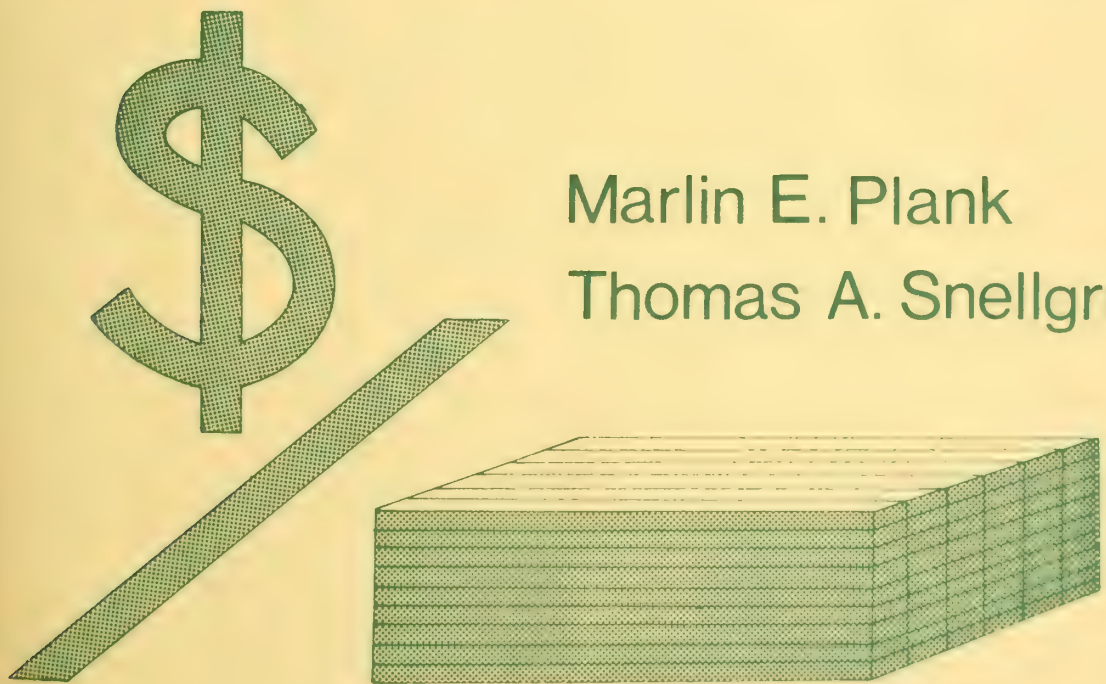

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# *AN EQUATION FOR ESTIMATING THE VALUE AND VOLUME OF WESTERN LARCH TREES*

*Reference Abstract*

Plank, Marlin E., and Thomas A. Snellgrove.
1978. An equation for estimating the value and volume of western larch trees. USDA For. Serv. Res. Pap. PNW-231, 29 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This paper describes an equation for estimating the total sales value or the volume for western larch trees. The equation requires four easy-to-measure characteristics. Both the development and the application of the system are discussed.

KEYWORDS: Tree value, volume estimation, grading systems, western larch, *Larix occidentalis*.

## RESEARCH SUMMARY

*Research Paper PNW-231*

*1978*

This paper describes a system for estimating the lumber selling value and the total volume of western larch trees in a manner which is more accurate and more practical to apply than the conventional method of placing logs in discrete classes.

From a total sample of 576 trees selected from 21 different areas in northeastern Washington and northwestern Montana, 506 were used to develop a prediction model equation. The remaining 70 trees plus 100 trees from a followup study in northwestern Montana were used to test the equation.

The model contains four tree characteristics:

1. tree diameter,
2. tree height,
3. the number of limb-free and defect-free faces in the butt 16-foot log, and
4. total tree defect.

The prediction equations account for 86 percent of the total variation in tree value and 89 percent of the total lumber volume variation as measured by the $R^2$ values.

When the system was applied to the 70 trees withheld from the original data, the prediction was 2.8 percent above the actual total dollar value and 1.8 percent above the volume recovered in lumber. The supplemental 100-tree study showed a predicted value of 2.7 percent less than the actual, and the volume estimate was 0.9 percent greater than that actually recovered.

The system is faster and more objective than log grading, and training and checking of cruisers is easier.

## Introduction

This paper is a continuation of a successful effort to improve methods of estimating the value and volume of sawtimber in the Western United States. A system is described which estimates the lumber selling value or volume of western larch (*Larix occidentalis* Nutt.) trees in a manner which is simpler and easier to apply than the conventional method of placing logs in discrete classes.

Two other papers[1/] describe similar systems which are now being used to appraise Inland Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western white pine (*Pinus monticola* Dougl.). These papers document the advantages of using a continuous variable system; likewise they show a number of reasons why the method of using discrete log grades is often inadequate.

The following describes the system, its development, and illustrates its performance with western larch.

## Study Procedures

### SAMPLE

This tree grading system was developed by studying the quality-related characteristics and lumber yield from two western larch lumber recovery studies. These studies were conducted in northwestern Montana and northeastern Washington (fig. 1). The Montana study included 297 trees selected from 11 areas on the Flathead National Forest. This resulted in 1,469 sawn logs with a lumber tally volume of 187,303 board feet. In the Washington study, 279 trees were selected from 10 areas on the Okanogan National Forest and the lumber yield from the 1,341 logs was 201,092 board feet.

The sample areas were chosen to represent differences in tree size, stem quality, and site characteristics. Within each sample area, individual trees were selected on the basis of d.b.h. The average d.b.h. and height for the trees in the Montana study area were 19.8 inches and 109 feet. For the Washington study, average d.b.h. was 23.5 inches, and average height was 113 feet. Over both samples, the d.b.h. range was from 8 to 43 inches. The study trees were felled and bucked into saw logs according to normal industry practice. The visible surface characteristics of each log were recorded in detail after the logs were spread out in the mill yard.

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1/ Lane, Paul H., Marlin E. Plank, and John W. Henley. 1970. A new and easier way to estimate the quality of Inland Douglas-fir sawtimber. USDA For. Serv. Res. Pap. PNW-101, 9 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Snellgrove, Thomas A., Marlin E. Plank, and Paul H. Lane. 1973. An improved system for estimating the value of western white pine. USDA For. Serv. Res. Pap. PNW-166, 19 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

*Figure 1.--Range of western larch (shaded) and general locations (cross-hatched) of the 21 areas from which study trees were cut.*

The study logs were processed at two sawmills which were considered representative of those processing western larch. The logs were sawn under normal production conditions; that is, sawing the particular mill's usual lumber items with the intent of obtaining the highest value from each log. The lumber tally values and volumes were based on kiln-dried, surfaced lumber tally according to general industry practice.

## DEVELOPING THE PREDICTION MODEL

The determination of those tree characteristics most highly correlated with total value and volume of lumber began with the screening of 62 variables. Previous studies on other species have indicated which variables or combinations should be included in the screening process. A list of the independent variables that were examined can be found in appendix I. The principal methods used were the forward stepwise regression procedure and all possible regressions. The stepwise regression procedure was used to identify those individual tree characteristics that best represented the factors of tree volume, defect, and quality, and which were correlated with tree value or tree lumber tally volume. After this screening, the independent variables that had little or no correlation with tree value or volume or were too difficult or impossible to quantify in cruising were

omitted from further analysis. The remaining variables, along with alternative forms of the same variable, were further screened by means of the all possible regression procedure to choose the final variables for the model.

As previously mentioned, two separate studies were conducted. Separate analyses of the two studies were done concurrently. The same variables surfaced as being the most practical for application in timber appraisals and statistically accounting for the most variation in lumber volume and value. Consequently, the same model was chosen for the two studies.

Although the regression equations were statistically different for the two studies, a common regression was fitted to the data from both. A common regression line was chosen to provide a broader inference to the entire range of western larch, and the difference between the regression equations for the two studies is probably not of practical significance.

Four measurable characteristics survived as the most practical for application in timber appraisals and accounted for the most variation in lumber volume and value. They are:

1. tree diameter at breast height,
2. total tree height,
3. number of limb- and defect-free faces on the butt 16-foot log, and
4. estimated tree defect expressed as a percentage of gross volume.

These four characteristics together with several transformations[2/] of the same characteristics were selected as the best independent variables for the model. These variables along with lumber yield information were used to develop the regression equations for predicting total tree value (dollars) and lumber tally volume (board feet) on a tree basis. Total tree value (dependent variable) is determined by multiplying the lumber yield data found in appendix II by an appropriate price.

The following model equations are used for predicting total tree value and total lumber volume:

$$\text{Total tree value} = b_o + b_1(DEF)(D^2H) + b_2(NLDF16) + b_3(D) + b_4(H) + b_5(DEF^2)(D^2H) + b_6(D^2) + b_7(H/D) + b_8(D^2H)$$

2/ Transformations are constructed variables designed to account for interactions of independent variables, e.g., height over diameter (H/D).

$$\text{Total lumber volume} = b_o + b_1(DEF)(D^2H) + b_2(NLDF16) + b_3(D^2) + b_4(H) + b_5(DEF^2)(D^2H) + b_6(H^2) + b_7(H/D) + b_8(H/D)^2 + b_9(D^2H) \quad ;$$

where, $b_o$ is the Y intercept constant,
$b_i$ is the regression coefficient where i goes from 1 to 9,
D is tree diameter at breast height (inches),
H is total tree height (feet),
NLDF16 is the number of limb-free and defect-free faces in the 16-foot log, and
DEF is the estimated tree defect expressed as a percentage of gross cruise volume.

Coefficients for the value equation may be determined according to the steps in the section: How to Use the System.

Coefficients for the volume equation are as follows:

| | |
|---|---|
| Constant | = + 80.453880 |
| $(DEF)(D^2H)$ | = - .000088720520 |
| NLDF16 | = + 2.4064027 |
| $D^2$ | = + .67704661 |
| H | = - 5.5433410 |
| $(DEF^2)(D^2H)$ | = - .00000041939578 |
| $H^2$ | = + .033906473 |
| H/D | = + 8.9652163 |
| $(H/D)^2$ | = + .077834676 |
| $(D^2H)$ | = + .0083360138 |

The equations developed from the two lumber recovery studies account for 86 percent of the total variation in total dollar value, 89 percent of the total variation in lumber volume.

## How the System Performs

From the total sample of 576 trees, a subsample of 70 trees was randomly selected to test the performance of the estimating equations. The 70 trees were not used in the development of the equations. The four quality criteria measurements (d.b.h., height, faces, and defect) were recorded for each of the 70 trees. Predictions of the lumber selling value and lumber tally volume were then calculated.

Table 1 shows comparisions of estimated and actual values for the 70 test trees. Plots of the actual versus estimated tree values and volumes of individual trees are

Table 1--*A comparison of estimated and actual lumber selling value and lumber tally volume for 70 western larch trees*

| Unit | Estimated | Actual | Percent difference |
|---|---|---|---|
| Total value (dollars) | 3,429.96 | 3,337.23 | +2.8 |
| Total lumber tally volume (board feet) | 47,913 | 47,068 | +1.8 |

shown in figures 2 and 3. As shown in these figures, the estimates of value and volume are about equally split by the 45-degree line.

In 1971, a lumber recovery study was held in Troy, Montana, in which the four quality criteria were recorded for each of the 100 trees in the sample. Predictions of the lumber selling value and lumber tally volume were made using the coefficients developed from the two base studies.

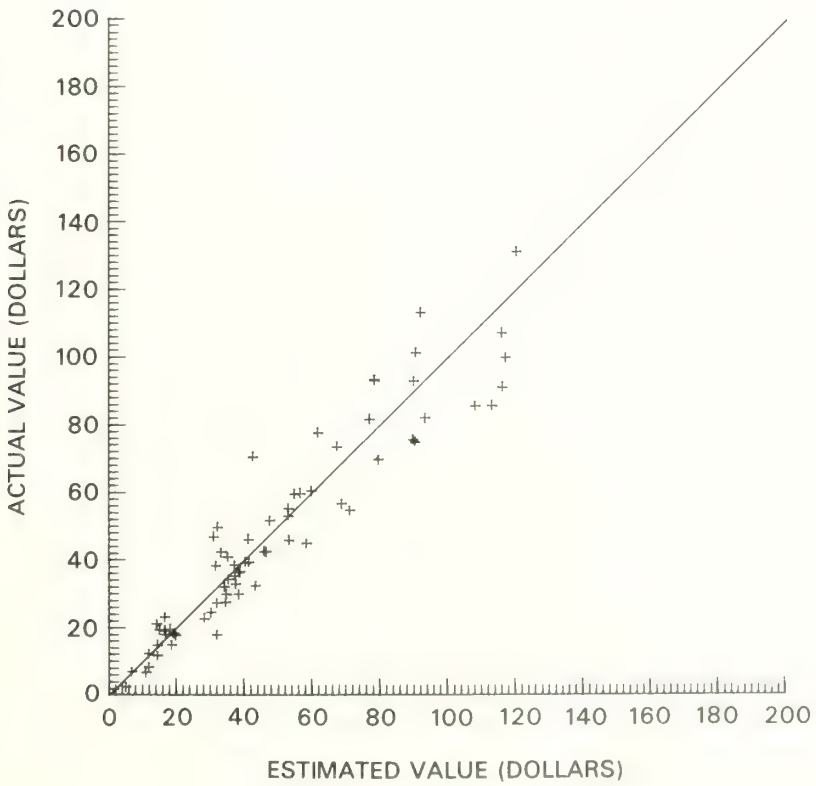


*Figure 2.--Plot of actual overestimated tree value. 70-tree sample.*

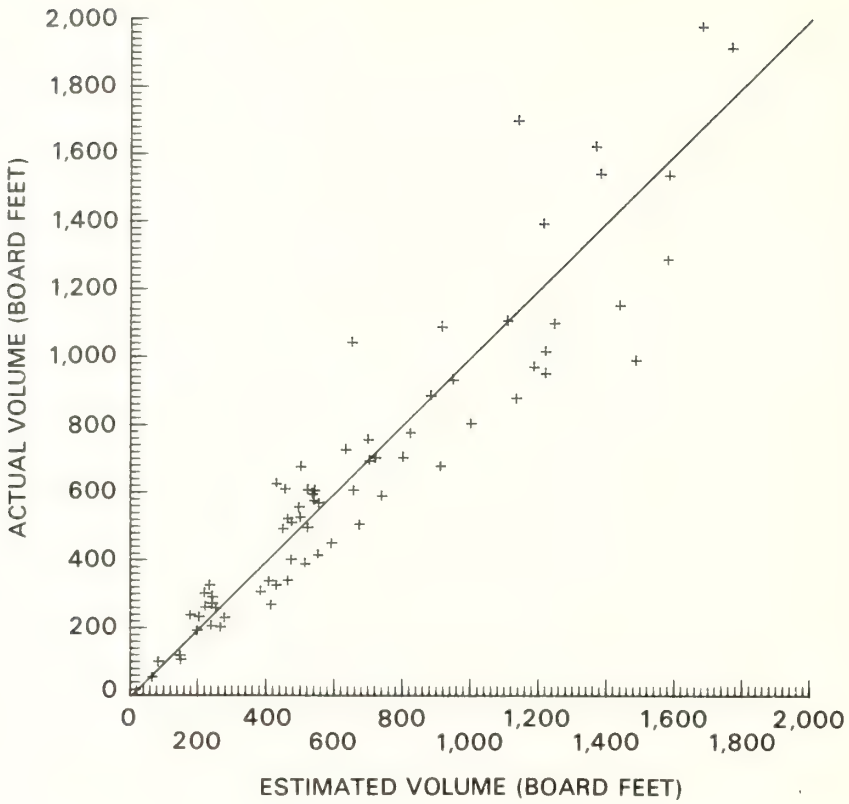


*Figure 3.--Plot of actual overestimated tree lumber tally volume. 70-tree sample.*

Table 2 shows the comparisons of the estimated and actual values for the 100 trees.

Figures 4 and 5 show plots of the actual versus estimated values and volumes for those trees.

Table 2-- *A comparison of estimated and actual lumber selling value and lumber tally volume for 100 western larch trees*

| Unit | Estimated | Actual | Percent difference |
|---|---|---|---|
| Total value (dollars) | 4,123.44 | 4,239.29 | -2.7 |
| Total lumber tally volume (board feet) | 53,624 | 53,159 | +0.9 |

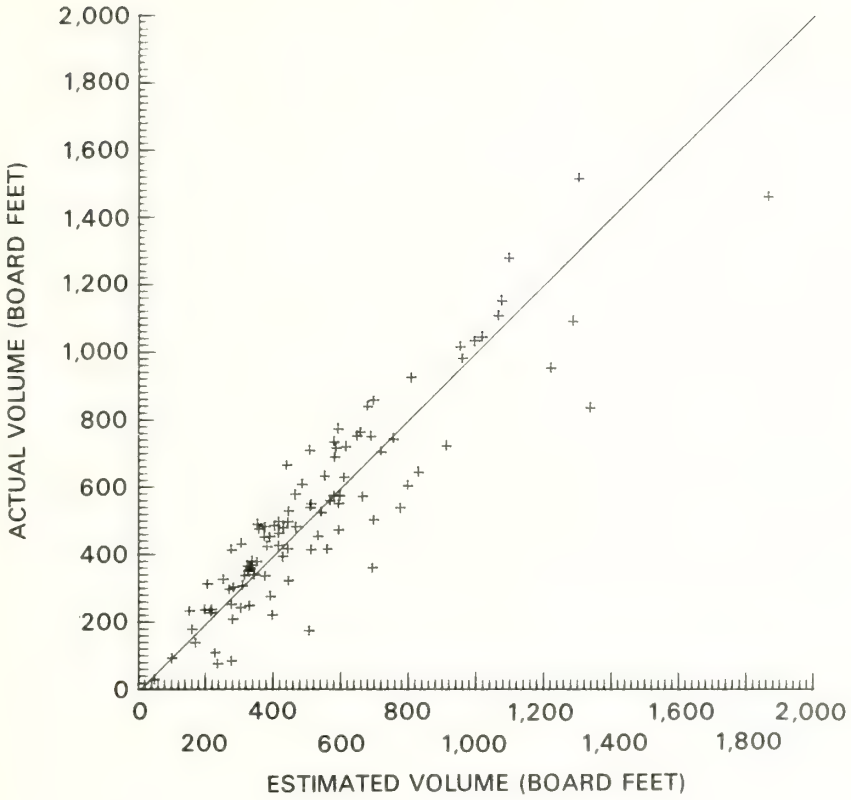


*Figure 4.--Plot of actual over- estimated tree lumber tally volume. 100-tree sample.*

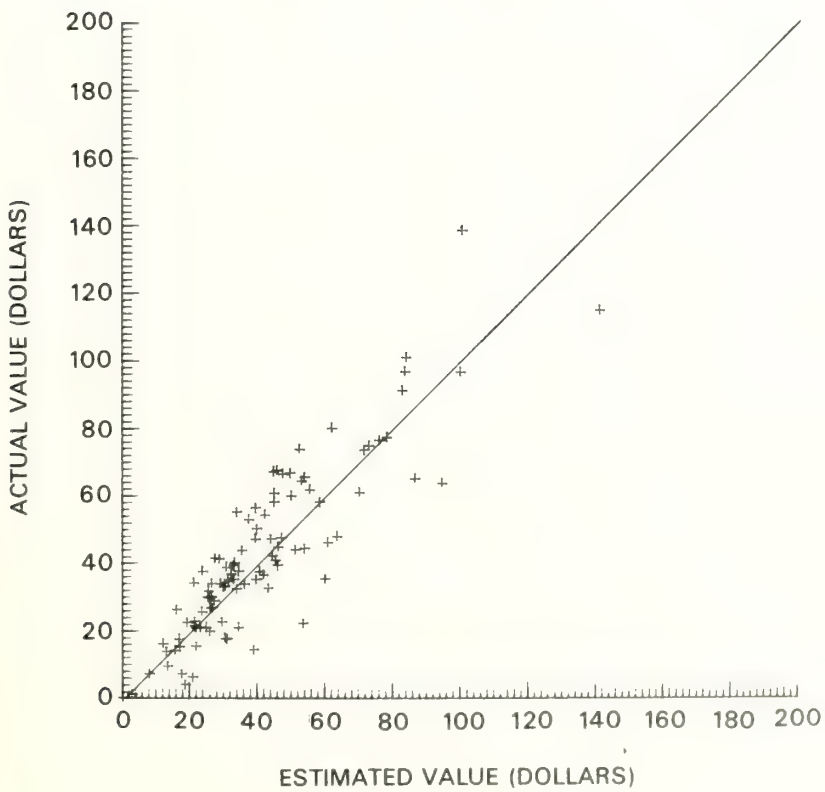


*Figure 5.--Plot of actual over- estimated tree value. 100-tree sample.*

## How to Use the System

Efficient use of this system requires computer facilities for making regression analyses. The tree characteristic data (the four quality criteria), the lumber grade yield data for each of the trees in the base study, and appropriate prices are needed in a form suitable for computer use. A listing of the data and the card format for the 506 trees is illustrated in appendix II.

To estimate the total lumber tally volume of a tree or group of trees, simply solve the following equation using the coefficients shown:

$$\text{Total lumber tally volume (board foot)} = +80.453880 - .000088720520(DEF)(D^2H) + 2.4064027(NLDF16) + .67704661(D^2 - 5.5433410(H) - .00000041939578(DEF^2)(D^2H) + .033906473(H + 8.9652163(H/D) + .077834676(H/D)^2 + .0083360138(D^2H).$$

The step-by-step procedure for estimating the selling value for a group of trees such as a sample for appraisal is as follows:

1. Select sample trees.

2. Measure and record for each sample tree the four characteristics:

   a. Tree diameter,
   b. Tree height,
   c. Number of limb-free and defect-free faces in the butt 16-foot log, and
   d. Tree defect.

3. Assign current or desired lumber price(s) such as those available from several industry price reporting services to each of the lumber grades recorded in the original base study.

4. Multiply these lumber prices by the lumber yield information shown in appendix II to obtain a total dollar value for each of the trees that are in the base study(s).

5. Use an appropriate multiple regression program such as the BMD program series[3/] to develop the value equation coefficients for the 506 trees. Use the computed

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[3/] Dixon, W. J., ed. 1964. BMD biomedical computer programs. Health Sciences Computing Facility, Department of Preventative Medicine and Public Health, School of Medicine, University of California at Los Angeles, Calif.

total dollar value (step 4) and the four tree characteristics and the following transformations:

Dependent Variables:

Total dollars/$D^2H$.

Independent Variables:

DEF
$DEF^2$
$NLDF16/D^2H$
$D/D^2H$
$H/D^2H$
$D^2/D^2H$
$H/D/D^2H$
$1/D^2H$

The dependent variable is divided by $D^2H$ to equalize variance, and all of the independent variables except DEF and $DEF^2$ are divided by $D^2H$ so that when the equation is untransformed it will appear as that on page 3 and 4. DEF and $DEF^2$ are not divided by $D^2H$ because they are already expressed as a percent of total volume.

6. Make a covariance analysis of the two base study value equations that result from applying new prices to obtain appropriate coefficients for the common equation (i.e., to obtain the weighted average equation applicable to the two base studies). If base studies are to be applied individually, use the appropriate equation for each area.

7. Solve the value equation for the selected sample trees in step 1 using coefficients developed in step 6.

## Conclusions

Field application tests of the system have demonstrated that it has a number of advantages over the conventional log grading method. It is faster to apply and thus more economical; it contains fewer judgment factors and therefore requires less experience by the cruiser and simplifies the training and checking of cruisers. Selling price is computed directly, the significant quality characteristics of each sample tree are recognized, and the computation procedures are relatively simple.

This system is similar to others which have been used successfully by the U.S. Forest Service in computing selling value on commercial timber sales in the northern Rocky Mountains. The performance and acceptance by both timber buyers and sellers indicate these systems are relatively

simple yet accurate methods for estimating the quality of sawtimber. The tests conducted thus far indicate that this system is applicable throughout the Inland Empire. Due to the expanse of the sample, it is the authors' opinion that it could be applied throughout the entire range of western larch.

## *Appendix I*

INDEPENDENT VARIABLES

Defect related variables

1. defect percent
2. defect percent squared

Presence or absence of:

3. bumps and burls
4. burls over 4 inches
5. conks
6. basal wounds
7. nonbasal wounds
8. all wounds

Length of:

9. basal wounds
10. nonbasal wounds
11. all wounds
12. basal wounds squared
13. nonbasal wounds squared
14. all wounds squared
15. total diameter of burls
16. total number of conks
17. total number of conks squared
18. number of knot clusters in butt 16-foot log
19. number of knot clusters in butt 32-foot log

Quality related variables

20. height to the first dead limb
21. height to the first live limb
22. size of the first dead limb
23. size of the first live limb
24. size of the largest limb in the butt 16-foot log
25. size of the largest limb in the butt 32-foot log
26. height to the start of the crown
27. crown ratio
28. crown length
29. height of clear bole allowing no defect
30. height of clear bole allowing defect
31. height of limb-free bole allowing no defect

32. height of limb-free bole allowing defect
33. total length of clear face in 4-foot minimum units in the butt 16-foot log
34. total length of clear face in 4-foot minimum units in the butt 32-foot log
35. total length of clear face in 8-foot minimum units in the butt 16-foot log
36. total length of clear face in 8-foot minimum units in the butt 32-foot log
37. number of 4-foot clear panels on the butt 16-foot log
38. number of 4-foot clear panels on the butt 32-foot log
39. number of clear 8-foot panels on the butt 16-foot log
40. number of clear 8-foot panels on the butt 32-foot log
41. number of clear 8-foot panels on the butt 16-foot log not allowing defect
42. number of clear 8-foot panels on the butt 16-foot log allowing defect
43. number of clear faces on the butt 16-foot log allowing defect
44. number of clear faces on the butt 16-foot log not allowing defect
45. number of clear faces on the butt 32-foot log allowing defect
46. number of clear faces on the butt 32-foot log not allowing defect
47. number of limb-free faces on the butt 16-foot log allowing defect
48. number of limb-free faces on the butt 16-foot log not allowing defect
49. number of limb-free faces on the butt 32-foot log allowing defect
50. number of limb-free faces on the butt 32-foot log not allowing defect

Volume related variables

51. d.b.h. - D
52. total height = H
53. 16-foot form class
54. taper
55. DH
56. D/H
57. $H/D$
58. $D^2$
59. $H^2$
60. $(D/H)^2$
61. $(H/D)^2$
62. $1/D^2H$

# *Appendix II*

## TREE QUALITY CHARACTERISTICS AND LUMBER YIELD DATA

The tree quality characteristics and lumber yield data for each of the 576 trees from the two base studies are listed according to the card format shown below.

LIST OF CHARACTERISTICS

| Columns | Data |
|---|---|
| 1 | study identifier |
| 2-4 | tree number |
| 5-7 | d.b.h. |
| 8-10 | total height |
| 11-13 | defect percent |
| 14 | number of limb-free and defect-free faces in the butt 16-foot log |
| 15-18 | volume of B Select lumber |
| 19-22 | volume of C Select lumber |
| 23-26 | volume of D Select lumber |
| 27-30 | volume of 1 Common lumber |
| 31-34 | volume of 2 Common lumber |
| 35-38 | volume of 3 Common lumber |
| 39-42 | volume of 4 Common lumber |
| 43-46 | volume of 5 Common lumber |
| 47-50 | volume of Select Structural lumber |
| 51-54 | volume of Construction lumber |
| 55-58 | volume of Standard lumber |
| 59-62 | volume of Utility lumber |
| 63-66 | volume of Economy lumber |
| 67-72 | total lumber tally volume |

# LIST OF DATA CARDS

| | | | | | | | V O L U M E | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | 8-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 1 | 1 | 306 | 150 | 12 | 4 | 80 | 205 | 212 | | 8 | 186 | 116 | 7 | 80 | 139 | 607 | 301 | 109 | 2050 |
| 1 | 2 | 225 | 129 | 12 | | | 24 | 33 | | 3 | 57 | 70 | 17 | | 202 | 109 | 94 | 198 | 807 |
| 1 | 4 | 227 | 132 | 14 | 3 | | 32 | 51 | | | 45 | 16 | | 32 | 128 | 211 | 131 | 39 | 685 |
| 1 | 5 | 336 | 146 | 49 | 2 | 11 | 112 | 308 | | | 147 | 86 | 32 | | 154 | 101 | 102 | 126 | 1179 |
| 1 | 6 | 235 | 110 | 11 | 3 | | 8 | 30 | | | 30 | 17 | 19 | | 100 | 285 | 157 | 120 | 766 |
| 1 | 7 | 202 | 120 | 6 | 2 | 9 | 36 | 44 | | | 36 | 58 | 10 | 27 | 277 | 37 | 57 | 71 | 662 |
| 1 | 8 | 146 | 84 | 13 | 4 | | 5 | 8 | | 7 | 5 | 9 | 5 | | 118 | 23 | 11 | | 191 |
| 1 | 9 | 273 | 147 | 12 | 4 | 21 | 132 | 101 | | | 72 | 48 | 8 | 112 | 296 | 183 | 192 | 172 | 1337 |
| 1 | 10 | 173 | 115 | 11 | 3 | | 8 | 26 | | 17 | 38 | 40 | 4 | | 140 | 123 | 26 | 24 | 446 |
| 1 | 11 | 162 | 108 | 4 | 3 | | 19 | 16 | | | | 36 | 32 | | 73 | 91 | | 68 | 335 |
| 1 | 12 | 239 | 114 | 4 | 4 | 12 | 13 | 26 | | 22 | 70 | 25 | 5 | | 128 | 228 | 73 | 34 | 636 |
| 1 | 13 | 201 | 112 | 11 | 3 | | 13 | 21 | | | 85 | 37 | | | 133 | 92 | 102 | 64 | 547 |
| 1 | 14 | 196 | 109 | 14 | 4 | | 8 | 19 | | 11 | 21 | 29 | 13 | | 33 | 114 | 135 | 123 | 506 |
| 1 | 15 | 183 | 114 | 13 | 3 | | | 59 | | | 58 | 45 | | | 107 | 113 | 100 | 43 | 525 |
| 1 | 17 | 233 | 128 | 22 | 4 | | 13 | 37 | | | 54 | 5 | 5 | | 272 | 110 | 126 | | 622 |
| 1 | 18 | 213 | 122 | 10 | 4 | | 38 | 110 | | 13 | 70 | 42 | 3 | 16 | 283 | 185 | 59 | 17 | 836 |
| 1 | 19 | 212 | 110 | 15 | 4 | | | 49 | | | 44 | 32 | | 21 | 173 | 198 | 127 | | 644 |
| 1 | 20 | 161 | 103 | 22 | 3 | | 4 | 8 | | | 19 | 26 | 4 | | 20 | 40 | 144 | 43 | 308 |
| 1 | 21 | 260 | 128 | 6 | 4 | | 30 | 100 | | 24 | 105 | 111 | 26 | | 267 | 223 | 243 | 123 | 1252 |
| 1 | 22 | 136 | 90 | 14 | 4 | | 8 | 5 | | | 12 | 20 | | | 53 | 16 | 46 | 32 | 192 |
| 1 | 23 | 247 | 114 | 7 | 3 | | 53 | 48 | | 18 | 71 | 150 | 15 | | 195 | 133 | 84 | 48 | 815 |
| 1 | 24 | 205 | 122 | 10 | 3 | 11 | 34 | 14 | | 11 | 55 | 31 | 28 | 101 | 139 | 58 | 38 | 16 | 536 |
| 1 | 25 | 163 | 113 | 6 | 4 | | | 8 | | 8 | 62 | 25 | 10 | 21 | 217 | 63 | 75 | | 489 |
| 1 | 26 | 176 | 97 | 12 | 3 | | 8 | 29 | | | 19 | 45 | 4 | 59 | 59 | 50 | 81 | 19 | 373 |
| 1 | 27 | 174 | 92 | 3 | 2 | | 34 | 24 | | | 32 | 71 | 19 | | 77 | 77 | 56 | 68 | 458 |
| 1 | 29 | 233 | 116 | 10 | 4 | 54 | 64 | 124 | | 24 | 51 | 11 | | 123 | 234 | 138 | 20 | | 843 |
| 1 | 30 | 227 | 120 | 16 | 4 | | 60 | 69 | | | 56 | 61 | | 21 | 212 | 141 | 98 | 99 | 817 |
| 1 | 31 | 226 | 112 | 6 | 3 | 13 | 16 | 79 | | 26 | 47 | | 9 | 53 | 245 | 230 | 79 | 16 | 813 |
| 1 | 32 | 223 | 108 | 6 | 3 | | 23 | 110 | | | 30 | 42 | 30 | 48 | 149 | 156 | 94 | 30 | 712 |
| 1 | 34 | 183 | 102 | 17 | 4 | | 21 | 49 | | | 33 | 28 | 20 | | 21 | 32 | 136 | 81 | 421 |
| 1 | 35 | 226 | 107 | 20 | 2 | | 55 | 61 | | 24 | 70 | 29 | 46 | 21 | 199 | 136 | 30 | 45 | 716 |
| 1 | 38 | 171 | 99 | | 3 | 27 | 8 | 13 | | 24 | 53 | 12 | 3 | | 215 | 56 | 48 | 12 | 471 |
| 1 | 39 | 162 | 94 | 14 | 3 | | | 22 | | | 30 | 27 | | 32 | 126 | 82 | 37 | 9 | 365 |
| 1 | 40 | 192 | 98 | 27 | 4 | | 27 | 18 | | | 33 | 25 | | 16 | 74 | 137 | 37 | 27 | 394 |
| 1 | 41 | 225 | 92 | 7 | 3 | | 16 | 28 | | 3 | 22 | 20 | 13 | 11 | 235 | 24 | 83 | 87 | 542 |
| 1 | 42 | 241 | 140 | 13 | 2 | 30 | 92 | 36 | | 30 | 59 | | 18 | 64 | 124 | 155 | 208 | 62 | 878 |
| 1 | 43 | 255 | 106 | 6 | 4 | 43 | 147 | 128 | | 21 | 83 | 31 | | 27 | 236 | 171 | 74 | | 961 |
| 1 | 44 | 207 | 106 | 13 | 4 | 11 | 19 | 56 | | 11 | 25 | 48 | | | 150 | 118 | 41 | 141 | 620 |
| 1 | 45 | 201 | 103 | 5 | 4 | | 15 | 74 | | 22 | 41 | 16 | 18 | 32 | 169 | 89 | 58 | | 534 |
| 1 | 46 | 207 | 100 | 10 | 4 | | 11 | 63 | | 21 | 22 | 55 | 13 | 43 | 130 | 125 | 103 | 20 | 606 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | VOLUME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | FCON | TOTAL |
| 1 | 47 | 260 | 132 | 13 | 3 | 80 | 198 | 134 | | | 143 | 52 | 16 | 33 | 300 | 242 | 272 | 16 | 1486 |
| 1 | 48 | 302 | 112 | 46 | 3 | 7 | 6 | 14 | | | 53 | 64 | 19 | | 89 | 152 | 543 | 407 | 1354 |
| 1 | 49 | 149 | 84 | 4 | 4 | | 20 | 33 | | 11 | 29 | 15 | | 11 | 59 | 91 | 41 | | 310 |
| 1 | 50 | 153 | 92 | 32 | 2 | | | 5 | | | 15 | 4 | 3 | | 16 | 22 | 38 | 52 | 155 |
| 1 | 51 | 194 | 91 | 45 | 2 | | | 4 | | | | | 7 | | | 11 | 8 | 87 | 117 |
| 1 | 52 | 255 | 100 | 14 | 4 | | 30 | 58 | | | 82 | 31 | 8 | | 197 | 348 | 160 | 63 | 985 |
| 1 | 53 | 190 | 92 | 13 | 4 | | 33 | 37 | | 38 | 17 | 29 | 15 | 32 | 107 | 96 | 59 | 43 | 506 |
| 1 | 54 | 194 | 89 | | 4 | | 13 | 47 | | 24 | 46 | 12 | 2 | 16 | 207 | 106 | 63 | 27 | 563 |
| 1 | 55 | 106 | 70 | 20 | 3 | | | 9 | | | | 4 | 3 | | 7 | 16 | | 14 | 53 |
| 1 | 56 | 137 | 76 | 8 | 4 | | 10 | 19 | | | 16 | 8 | 5 | | 76 | 16 | 16 | 8 | 174 |
| 1 | 57 | 152 | 72 | 42 | 4 | 3 | 18 | 7 | | 5 | 5 | 11 | | | 32 | | 16 | 24 | 121 |
| 1 | 58 | 190 | 86 | 19 | 4 | . | 6 | 40 | | | 32 | | | | 43 | 125 | 53 | | 299 |
| 1 | 59 | 181 | 87 | 9 | 4 | | 26 | 27 | | | 5 | 66 | 8 | | 90 | 100 | 106 | 59 | 487 |
| 1 | 60 | 256 | 98 | 10 | 4 | | 16 | 73 | | | 66 | 33 | | 32 | 96 | 223 | 346 | 66 | 951 |
| 1 | 61 | 194 | 93 | 5 | 4 | | 18 | | | | 50 | 28 | 16 | | 203 | 53 | 65 | 7 | 440 |
| 1 | 62 | 216 | 95 | 4 | 3 | | 37 | 69 | | | 37 | 23 | | 91 | 155 | 179 | 120 | | 711 |
| 1 | 63 | 207 | 90 | 15 | 3 | 7 | | 33 | | 13 | 70 | 19 | 3 | | 115 | 224 | 154 | 14 | 652 |
| 1 | 65 | 197 | 89 | | 4 | | | 9 | | | 8 | 2 | 1 | 8 | 12 | 33 | 24 | 4 | 574 |
| 1 | 66 | 132 | 80 | 25 | 3 | | | 14 | | | 14 | 8 | 10 | | 35 | 34 | 43 | 22 | 180 |
| 1 | 67 | 209 | 87 | 12 | 4 | | 9 | 47 | | | 30 | 17 | | 9 | 102 | 180 | 152 | 63 | 609 |
| 1 | 68 | 264 | 100 | 16 | 4 | 31 | 51 | 101 | | 11 | 107 | 83 | 13 | 37 | 123 | 130 | 164 | 74 | 925 |
| 1 | 69 | 253 | 96 | 10 | 4 | 8 | 44 | 91 | | 11 | 84 | 58 | 23 | | 135 | 293 | 130 | 90 | 967 |
| 1 | 70 | 262 | 104 | 17 | 4 | 21 | 40 | 111 | | | 118 | 67 | 30 | 16 | 133 | 202 | 277 | 51 | 1066 |
| 1 | 71 | 302 | 106 | 59 | 4 | | 7 | 105 | | | 43 | 23 | | | 32 | | 96 | 75 | 381 |
| 1 | 72 | 207 | 92 | | 3 | | 24 | 20 | | | 20 | 62 | 5 | 21 | 53 | 37 | 198 | 71 | 511 |
| 1 | 73 | 151 | 85 | 16 | 1 | | | 11 | | | 40 | 17 | | | 16 | 42 | 88 | 27 | 241 |
| 1 | 74 | 265 | 145 | 12 | 4 | 23 | 20 | 155 | | | 134 | 25 | 8 | 96 | 379 | 317 | 101 | | 1258 |
| 1 | 75 | 231 | 139 | 1 | 3 | | 20 | 19 | | | 183 | | 15 | 155 | 296 | 243 | 143 | 32 | 1106 |
| 1 | 76 | 177 | 126 | 9 | 4 | | | 16 | | 13 | 37 | 16 | | | 276 | 121 | 65 | 16 | 560 |
| 1 | 77 | 255 | 146 | 6 | 3 | 5 | 55 | 212 | | | 205 | 17 | | 143 | 395 | 151 | 191 | 20 | 1394 |
| 1 | 78 | 204 | 140 | 14 | 4 | 11 | 33 | 58 | | 7 | 73 | 60 | 10 | 58 | 185 | 117 | 147 | 54 | 813 |
| 1 | 79 | 257 | 144 | 15 | 4 | 13 | 32 | 158 | | 27 | 115 | 27 | | 21 | 225 | 228 | 170 | 28 | 1044 |
| 1 | 80 | 135 | 114 | | 3 | | 6 | 15 | | 7 | 22 | 34 | | 11 | 144 | 44 | 73 | 11 | 367 |
| 1 | 82 | 249 | 134 | 5 | 4 | | 55 | 101 | | 17 | 118 | 25 | | | 482 | 154 | 173 | 29 | 1154 |
| 1 | 83 | 125 | 100 | 6 | 3 | | | | | | 16 | 7 | 10 | 9 | 65 | 46 | 29 | 9 | 191 |
| 1 | 84 | 194 | 126 | | 4 | | 38 | 43 | | 11 | 120 | 26 | 10 | 59 | 182 | 96 | 53 | 11 | 649 |
| 1 | 85 | 244 | 137 | 9 | 3 | | | 62 | | | 175 | 21 | 9 | | 187 | 284 | 474 | 24 | 1236 |
| 1 | 86 | 106 | 96 | | 4 | | | | | | | 3 | 5 | 11 | 11 | 22 | 11 | 9 | 72 |
| 1 | 87 | 214 | 135 | 5 | 4 | | 57 | 153 | | | 41 | 23 | 18 | 48 | 195 | 140 | 170 | 22 | 867 |
| 1 | 88 | 233 | 131 | 6 | 4 | 11 | 55 | 112 | | | 52 | 21 | 24 | 96 | 361 | 260 | 36 | 5 | 1033 |

| | | | | | | VOLUME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STUDY | TREE | DBH | TOT HT | PCNT DEF | MLF16 | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 1 | 89 | 247 | 137 | 5 | 4 | | 21 | 101 | | 13 | 78 | 24 | 8 | 21 | 177 | 152 | 178 | 27 | 800 |
| 1 | 90 | 226 | 130 | 13 | 4 | | 5 | 46 | | | 145 | 33 | | 80 | 310 | 149 | 52 | 64 | 884 |
| 1 | 91 | 354 | 132 | 10 | 3 | | | 32 | | | 119 | 52 | 8 | 32 | 331 | 453 | 444 | 85 | 1556 |
| 1 | 92 | 248 | 134 | 9 | 2 | | | 11 | | | 50 | 40 | | | 139 | 221 | 388 | 28 | 877 |
| 1 | 93 | 314 | 145 | 16 | 3 | | 44 | 45 | | 14 | 152 | 64 | 7 | 38 | 592 | 222 | 522 | 172 | 1872 |
| 1 | 94 | 214 | 116 | 16 | 3 | | | 26 | | 4 | 62 | 30 | 5 | | 175 | 88 | 225 | 72 | 687 |
| 1 | 95 | 402 | 135 | 76 | 4 | | | 36 | | | 11 | 45 | 16 | 14 | 218 | 176 | 374 | 728 | 1618 |
| 1 | 96 | 261 | 136 | 6 | 4 | 13 | 57 | 113 | | 11 | 204 | 25 | 7 | | 336 | 345 | 140 | 11 | 1262 |
| 1 | 98 | 327 | 147 | 15 | 4 | | 111 | 237 | | 29 | 124 | 44 | | 27 | 337 | 252 | 280 | 218 | 1659 |
| 1 | 99 | 239 | 148 | 11 | 3 | | | 21 | | | 56 | 3 | | 90 | 513 | 262 | 168 | 80 | 1193 |
| 1 | 100 | 283 | 161 | 18 | 4 | | | 40 | | | 77 | 29 | 14 | 48 | 123 | 361 | 743 | 172 | 1607 |
| 1 | 102 | 155 | 125 | 16 | 2 | | 5 | 17 | | | 3 | 36 | 8 | 43 | 139 | 71 | 134 | 24 | 480 |
| 1 | 103 | 278 | 156 | 23 | 2 | | | | | | 55 | 66 | | 16 | 347 | 478 | 280 | 194 | 1436 |
| 1 | 104 | 255 | 160 | 8 | 4 | 34 | 16 | 94 | | 16 | 121 | 7 | 5 | 246 | 525 | 281 | 123 | 16 | 1484 |
| 1 | 105 | 228 | 134 | 21 | 4 | | | 54 | | | 63 | 26 | 11 | | 138 | 127 | 144 | 136 | 699 |
| 1 | 106 | 203 | 125 | 5 | 4 | | | 33 | | 32 | 100 | 31 | 11 | | 372 | 48 | 113 | 30 | 770 |
| 1 | 107 | 334 | 138 | 13 | 3 | | 132 | 150 | | 11 | 153 | 54 | 32 | 43 | 281 | 501 | 560 | 312 | 2229 |
| 1 | 108 | 180 | 120 | 6 | 2 | | 11 | 13 | | 5 | 61 | 53 | | 69 | 234 | 64 | 84 | 36 | 630 |
| 1 | 109 | 158 | 107 | 10 | 4 | | | 21 | | 8 | 9 | 30 | | 16 | 170 | 35 | 47 | 69 | 413 |
| 1 | 110 | 137 | 109 | 33 | 2 | | | 5 | | 3 | | 10 | 14 | | 21 | 42 | 86 | 58 | 239 |
| 1 | 111 | 140 | 104 | 5 | 4 | | | 6 | | 16 | 15 | 12 | 9 | | 71 | | 66 | 64 | 259 |
| 1 | 112 | 155 | 110 | 11 | 3 | | | 18 | | | 10 | 7 | 6 | | 171 | 16 | 61 | 95 | 386 |
| 1 | 113 | 207 | 142 | 7 | 3 | | 35 | 145 | | | 68 | 3 | 5 | 43 | 261 | 75 | 91 | 54 | 780 |
| 1 | 114 | 214 | 126 | 7 | 1 | | | 36 | | | 25 | 58 | 23 | 19 | 157 | 200 | 115 | 90 | 723 |
| 1 | 115 | 165 | 114 | 12 | 4 | | | 24 | | 11 | 51 | 42 | 10 | | 128 | 70 | 58 | 89 | 483 |
| 1 | 116 | 255 | 98 | 39 | 4 | | 40 | 86 | | | 24 | 21 | 10 | | 69 | 84 | 228 | 127 | 689 |
| 1 | 117 | 177 | 105 | 39 | 4 | | 12 | 8 | | | 30 | 12 | 16 | | 29 | 45 | 82 | 57 | 291 |
| 1 | 119 | 198 | 130 | 7 | 3 | | 19 | 68 | | 19 | 72 | 21 | 10 | 63 | 96 | 109 | 31 | 96 | 610 |
| 1 | 121 | 169 | 101 | 15 | 3 | | | 6 | | 8 | 21 | 24 | | 21 | 123 | 50 | 64 | | 317 |
| 1 | 122 | 172 | 108 | 23 | 4 | | 4 | 30 | | 11 | 8 | 21 | | 16 | 116 | 85 | 7 | | 298 |
| 1 | 123 | 256 | 130 | 7 | 4 | 11 | 67 | 101 | | | 54 | 49 | | 95 | 272 | 234 | 65 | 139 | 1087 |
| 1 | 124 | 184 | 114 | 20 | 3 | | | 18 | | | 48 | 35 | | 27 | 236 | 147 | 81 | 11 | 605 |
| 1 | 126 | 168 | 113 | 11 | 4 | | 8 | 28 | | | 59 | 10 | 5 | 22 | 149 | | 107 | 43 | 431 |
| 1 | 127 | 153 | 108 | 30 | 4 | | 13 | | | | 12 | 35 | | 16 | 61 | 110 | 45 | 21 | 313 |
| 1 | 126 | 152 | 102 | 11 | 2 | | | 10 | | 8 | 16 | 7 | 15 | 55 | 110 | 99 | 34 | 53 | 397 |
| 1 | 129 | 144 | 100 | 10 | 4 | | | 10 | | 8 | 15 | 25 | | 16 | 75 | 59 | 75 | 11 | 294 |
| 1 | 130 | 144 | 88 | 31 | 1 | | | | | 7 | 9 | 15 | | | 21 | 43 | 42 | 8 | 145 |
| 1 | 131 | 208 | 126 | 4 | 2 | | | 129 | | 34 | 81 | 17 | 8 | 96 | 249 | 121 | 158 | | 893 |
| 1 | 132 | 152 | 107 | 14 | 3 | | | 23 | | 11 | 23 | 18 | | | 102 | 50 | | 70 | 297 |
| 1 | 133 | 144 | 110 | 21 | 4 | | | 23 | | | 30 | | 5 | 16 | 149 | 16 | 34 | | 273 |

| | | | | | | VOLUME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 1 | 134 | 143 | 80 | 19 | 3 | | | 3 | | | 15 | 7 | 24 | | 43 | 16 | 68 | 59 | 235 |
| 1 | 135 | 158 | 108 | 6 | 3 | | | 8 | | | 43 | 46 | 10 | | 160 | 49 | 107 | 19 | 442 |
| 1 | 136 | 124 | 92 | 7 | 4 | | | 4 | 15 | | 9 | 12 | 11 | | 102 | 11 | 62 | | 226 |
| 1 | 137 | 214 | 124 | 10 | 3 | | 13 | 33 | | | 89 | 39 | 23 | 11 | 235 | 133 | 88 | 54 | 710 |
| 1 | 138 | 161 | 107 | 10 | 4 | | 27 | 24 | 8 | | 28 | 41 | 8 | | 127 | 61 | 60 | 68 | 452 |
| 1 | 139 | 168 | 108 | 7 | 3 | | | 31 | | | 47 | 24 | 3 | | 123 | 69 | 16 | 91 | 404 |
| 1 | 140 | 125 | 107 | 5 | 3 | | 6 | 15 | | | 20 | 4 | 5 | | 91 | 43 | 16 | 32 | 232 |
| 1 | 142 | 195 | 130 | 10 | 4 | | 11 | 23 | | | 57 | 10 | 4 | 64 | 196 | 104 | 85 | | 554 |
| 1 | 143 | 196 | 112 | 4 | 2 | | 8 | 70 | | 27 | 79 | 43 | 14 | 21 | 203 | 77 | 27 | 86 | 655 |
| 1 | 144 | 255 | 112 | 10 | 4 | 72 | 96 | 213 | | 13 | 41 | 5 | 17 | 91 | 144 | 194 | 110 | 49 | 1045 |
| 1 | 145 | 237 | 116 | 3 | 4 | | 57 | 43 | | 16 | 96 | 21 | 5 | 37 | 314 | 186 | 235 | 51 | 1061 |
| 1 | 147 | 197 | 113 | 6 | 4 | | 11 | 21 | | 4 | 35 | 35 | 5 | | 151 | 122 | 200 | 123 | 707 |
| 1 | 148 | 162 | 100 | | 3 | | 5 | 61 | | 22 | 29 | 10 | | | 134 | 74 | 20 | 15 | 370 |
| 1 | 149 | 196 | 116 | 6 | 4 | 8 | 18 | 96 | | | 25 | 48 | 8 | 37 | 152 | 89 | 42 | 54 | 567 |
| 1 | 150 | 229 | 118 | 6 | 4 | | 13 | 57 | | 8 | 76 | 59 | 21 | 64 | 218 | 157 | 269 | 56 | 998 |
| 1 | 151 | 189 | 114 | 2 | 4 | | 20 | 62 | | 16 | 24 | 24 | 12 | 53 | 85 | 198 | 121 | | 615 |
| 1 | 153 | 209 | 118 | 7 | 4 | | 45 | 79 | | 22 | 40 | 50 | 8 | 53 | 150 | 176 | 128 | 37 | 788 |
| 1 | 155 | 227 | 110 | 11 | 4 | | 10 | 27 | | 22 | 36 | 15 | 5 | 20 | 235 | 297 | 245 | 15 | 927 |
| 1 | 156 | 158 | 92 | 15 | 4 | 13 | 32 | 18 | | 16 | 37 | 10 | | | 64 | 88 | | 31 | 309 |
| 1 | 157 | 229 | 116 | 13 | 4 | | 44 | 38 | | 16 | 37 | 13 | 5 | 58 | 68 | 152 | 163 | 34 | 628 |
| 1 | 158 | 164 | 104 | 22 | 4 | | | 20 | | | 7 | 4 | | | 83 | 61 | 16 | | 191 |
| 1 | 159 | 162 | 101 | 11 | 4 | | 14 | 27 | | 8 | 30 | | | 32 | 111 | 73 | 59 | 30 | 384 |
| 1 | 160 | 226 | 122 | 6 | 4 | | 94 | 79 | | 11 | 84 | 37 | | 16 | 193 | 173 | 298 | 21 | 1006 |
| 1 | 161 | 195 | 110 | 6 | 4 | | 11 | 111 | | | 64 | 35 | 13 | 69 | 142 | 172 | 27 | 9 | 653 |
| 1 | 162 | 273 | 125 | 16 | 4 | 36 | 55 | 90 | | 5 | 63 | 34 | 20 | 27 | 339 | 309 | 96 | 83 | 1217 |
| 1 | 163 | 151 | 104 | | 4 | | | 34 | | 26 | 26 | | 5 | | 108 | 56 | 48 | | 303 |
| 1 | 164 | 167 | 100 | | 4 | | 19 | 35 | | 24 | 55 | 21 | | 22 | 112 | | 32 | 32 | 352 |
| 1 | 165 | 170 | 102 | 10 | 3 | | | 45 | | 16 | 17 | 47 | 8 | 16 | 47 | 155 | 43 | 11 | 405 |
| 1 | 166 | 115 | 89 | | 4 | | 3 | 7 | | 4 | 10 | | 5 | | 64 | 22 | 8 | 11 | 134 |
| 1 | 167 | 175 | 108 | | 4 | | 44 | 58 | | 16 | 14 | 25 | | 11 | 96 | 83 | 71 | 12 | 430 |
| 1 | 168 | 109 | 90 | | 4 | | | | | | 10 | 8 | | | 60 | 52 | 9 | | 139 |
| 1 | 169 | 84 | 77 | | 1 | | | | | | 4 | | | | | | 33 | 12 | 49 |
| 1 | 170 | 141 | 98 | | 4 | | | 22 | | | 7 | 11 | 8 | 32 | 104 | 32 | 45 | | 261 |
| 1 | 171 | 176 | 108 | 3 | 4 | | 40 | 115 | | | 56 | 20 | | 53 | 192 | 33 | 20 | 27 | 556 |
| 1 | 172 | 214 | 104 | 15 | 4 | 32 | 22 | 75 | | | 48 | 24 | | 48 | 64 | 170 | 50 | 80 | 613 |
| 1 | 174 | 134 | 90 | | 4 | | | 8 | | 4 | 19 | 27 | 4 | | 136 | 29 | | | 227 |
| 1 | 175 | 215 | 127 | 3 | 4 | 43 | 50 | 78 | | | 76 | 66 | 11 | 67 | 238 | 190 | 85 | 17 | 923 |
| 1 | 176 | 195 | 122 | 8 | 4 | | 12 | 59 | | 8 | 90 | 26 | 10 | 21 | 314 | 93 | 44 | 10 | 687 |
| 1 | 178 | 253 | 112 | 20 | 4 | 13 | 42 | 112 | | 13 | 72 | 45 | | 48 | 197 | 178 | 129 | 55 | 904 |
| 1 | 179 | 239 | 124 | 6 | 4 | | 13 | 45 | | 8 | 34 | 52 | 21 | | 429 | 226 | 260 | 34 | 1122 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | V O L U M E | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 1 | 180 | 278 | 116 | 8 | 3 | 67 | 176 | 264 | | 11 | 57 | 75 | 32 | | 171 | 297 | 146 | 82 | 1378 |
| 1 | 181 | 285 | 130 | 22 | 3 | 13 | 107 | 129 | | | 134 | 102 | 24 | | 235 | 343 | 198 | 131 | 1416 |
| 1 | 183 | 142 | 93 | | 3 | | | 8 | | 5 | 31 | 5 | | 37 | 59 | 102 | 48 | 8 | 303 |
| 1 | 185 | 207 | 87 | 24 | 2 | | | 13 | | | 24 | 18 | 11 | | 27 | 88 | 94 | 109 | 384 |
| 1 | 186 | 164 | 93 | 16 | 3 | 6 | 20 | 24 | | 11 | 34 | 12 | 3 | | 11 | 132 | 66 | 5 | 324 |
| 1 | 187 | 136 | 95 | 14 | 3 | | | | | | 14 | 18 | 10 | | 16 | 48 | 59 | 11 | 176 |
| 1 | 188 | 103 | 64 | 20 | 2 | | | 3 | | | 3 | 3 | 5 | | | | 11 | 11 | 36 |
| 1 | 190 | 213 | 110 | 6 | 3 | 26 | 55 | 99 | | | 23 | 20 | 8 | 21 | 210 | 172 | 28 | | 662 |
| 1 | 192 | 137 | 90 | 30 | 3 | | 4 | 11 | | | 15 | 5 | 5 | | 32 | 11 | 32 | 23 | 138 |
| 1 | 194 | 232 | 108 | 12 | 4 | 42 | 42 | 132 | | | 137 | | 8 | 48 | 171 | 188 | 183 | 23 | 974 |
| 1 | 195 | 217 | 108 | 6 | 4 | | 52 | 79 | | | 89 | 37 | 5 | 48 | 198 | 179 | 43 | 81 | 811 |
| 1 | 196 | 216 | 97 | 37 | 4 | | 3 | 5 | | | 28 | 22 | 11 | | 47 | 128 | 115 | 73 | 432 |
| 1 | 197 | 222 | 96 | 11 | 4 | | 46 | 55 | | 8 | 113 | 6 | 20 | 16 | 160 | 147 | 394 | 12 | 977 |
| 1 | 199 | 156 | 90 | 41 | 2 | | 9 | 20 | | 11 | 9 | 3 | 16 | 37 | 11 | | 14 | 12 | 142 |
| 1 | 200 | 159 | 94 | 30 | 3 | | | 19 | | | 16 | 9 | | | 11 | 41 | 67 | 32 | 195 |
| 1 | 201 | 135 | 84 | 7 | 4 | | | 5 | | | 8 | 15 | 14 | | 80 | | 37 | 32 | 191 |
| 1 | 202 | 223 | 116 | 12 | 4 | 21 | 34 | 75 | | | 54 | 30 | 24 | 80 | 231 | 103 | 80 | 23 | 755 |
| 1 | 203 | 168 | 36 | | 4 | | | 33 | | | 51 | 13 | 13 | 51 | 32 | 56 | 94 | 9 | 352 |
| 1 | 204 | 166 | 87 | 11 | 3 | | 14 | 14 | | | 5 | 10 | 20 | | 39 | 70 | 76 | 24 | 272 |
| 1 | 205 | 177 | 101 | 24 | 3 | | 8 | 17 | | | 65 | 22 | | | 116 | 28 | 9 | 171 | 436 |
| 1 | 206 | 237 | 114 | 22 | 4 | | 7 | 52 | | 16 | 29 | 64 | 23 | 21 | 205 | 147 | 119 | 106 | 789 |
| 1 | 210 | 202 | 104 | 11 | 4 | | 51 | 88 | | 13 | 54 | 22 | 5 | | 154 | 198 | 246 | 25 | 766 |
| 1 | 211 | 183 | 103 | 3 | 3 | | 39 | 47 | | | 17 | 28 | | 48 | 168 | 64 | 83 | 61 | 555 |
| 1 | 212 | 249 | 109 | 37 | 4 | | 12 | 59 | | | | 32 | 9 | 27 | 136 | 94 | 318 | 150 | 837 |
| 1 | 213 | 311 | 105 | 15 | 3 | | 21 | 123 | | | 224 | 39 | 9 | | 288 | 304 | 359 | 32 | 1399 |
| 1 | 214 | 226 | 96 | 11 | 4 | | | 92 | | 13 | 49 | 20 | 11 | | 214 | 158 | 64 | 29 | 650 |
| 1 | 216 | 184 | 94 | 26 | 4 | | 24 | 52 | | | 3 | 13 | | 43 | 60 | 69 | 25 | | 289 |
| 1 | 217 | 152 | 92 | 5 | 4 | 6 | | 13 | | 8 | 38 | 10 | 16 | | 121 | | 16 | 48 | 276 |
| 1 | 218 | 325 | 149 | 34 | 4 | 68 | 70 | 103 | | | 62 | 87 | 14 | 27 | 296 | 514 | 418 | 430 | 2089 |
| 1 | 219 | 255 | 130 | 20 | 3 | | 23 | 100 | | | 106 | 40 | 13 | 21 | 130 | 249 | 290 | 95 | 1067 |
| 1 | 220 | 321 | 153 | 34 | | 77 | | 48 | | | 123 | 49 | 8 | 32 | 103 | 341 | 471 | 631 | 1883 |
| 1 | 222 | 377 | 139 | 45 | 4 | 77 | 94 | 84 | | | 25 | 58 | 24 | 93 | 225 | 231 | 649 | 412 | 1972 |
| 1 | 223 | 279 | 145 | 29 | 3 | 29 | 70 | 130 | | 13 | 59 | 53 | 15 | | 57 | 189 | 427 | 194 | 1236 |
| 1 | 224 | 342 | 126 | 39 | 3 | | | 27 | | | 64 | 65 | 42 | 78 | 268 | 286 | 381 | 442 | 1653 |
| 1 | 225 | 133 | 102 | 4 | 4 | 11 | 39 | 23 | | 16 | 27 | 15 | | 32 | 64 | 43 | 16 | 11 | 297 |
| 1 | 226 | 181 | 109 | 7 | 4 | | 40 | 45 | | 17 | 63 | 20 | 5 | 64 | 134 | 100 | | | 488 |
| 1 | 228 | 116 | 80 | | 4 | | | 11 | | 8 | 21 | 5 | | 16 | 111 | 16 | 12 | | 200 |
| 1 | 229 | 94 | 77 | | 3 | | | 4 | | | | 5 | 5 | 9 | | 11 | 11 | 11 | 56 |
| 1 | 230 | 161 | 96 | | 4 | 11 | 20 | 37 | | 8 | 18 | 8 | | 27 | 142 | 53 | 11 | | 335 |
| 1 | 231 | 136 | 97 | 10 | 4 | 5 | | 28 | | 16 | 27 | 20 | 5 | 43 | 59 | 16 | | 22 | 241 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | V O L U M E | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 1 | 232 | 141 | 94 | | 4 | | 19 | 37 | | | 33 | 21 | 5 | 32 | 48 | 27 | 32 | 7 | 261 |
| 1 | 234 | 192 | 107 | | 4 | | 23 | 76 | | 13 | 56 | 24 | 3 | 16 | 219 | 59 | 35 | 11 | 535 |
| 1 | 235 | 169 | 91 | 13 | 4 | | 15 | 35 | | 8 | 23 | 36 | 5 | 16 | 102 | | 22 | 16 | 278 |
| 1 | 236 | 112 | 95 | | 4 | | 11 | 5 | | 5 | 17 | | 11 | 27 | 27 | 27 | 11 | | 141 |
| 1 | 237 | 105 | 86 | 9 | 4 | | 5 | | | | 16 | | 6 | 27 | 9 | 32 | 16 | 15 | 126 |
| 1 | 238 | 136 | 106 | 8 | 2 | | 28 | 49 | | 8 | 30 | 5 | 8 | 11 | 118 | 16 | 27 | | 300 |
| 1 | 239 | 116 | 86 | 10 | 3 | | | 7 | | | 5 | 8 | 5 | | 35 | 14 | 32 | 20 | 126 |
| 1 | 240 | 165 | 108 | 8 | 4 | | 11 | 43 | | 35 | 92 | 18 | | 37 | 123 | 114 | 32 | 33 | 538 |
| 1 | 241 | 165 | 108 | 3 | 4 | | 6 | 34 | | 27 | 79 | 4 | 3 | 32 | 85 | 61 | 9 | 27 | 367 |
| 1 | 242 | 143 | 106 | | 4 | 5 | 15 | 37 | | | 11 | 30 | 3 | 32 | 96 | 43 | 31 | 16 | 319 |
| 1 | 243 | 117 | 94 | | 4 | | | 10 | | | 10 | 14 | 9 | 11 | 70 | | 45 | 11 | 180 |
| 1 | 244 | 172 | 108 | 6 | 3 | | 24 | 42 | | | 66 | 42 | 14 | | 134 | 94 | 73 | | 489 |
| 1 | 245 | 143 | 96 | 13 | 4 | | 16 | 8 | | 5 | 16 | 11 | 10 | | 36 | 67 | 5 | | 174 |
| 1 | 246 | 106 | 80 | 11 | 3 | | | 5 | | 3 | 8 | 6 | 13 | 21 | 11 | | 21 | 11 | 99 |
| 1 | 247 | 152 | 94 | 4 | 4 | | 13 | 47 | | 16 | 34 | 32 | 3 | 83 | 64 | 11 | 11 | | 314 |
| 1 | 248 | 139 | 90 | 19 | 4 | | 7 | 12 | | 6 | 10 | 10 | | | 39 | | 60 | 7 | 151 |
| 1 | 250 | 235 | 108 | 20 | 4 | | 98 | 33 | | 11 | 70 | 42 | | 64 | 155 | 66 | 89 | 30 | 658 |
| 1 | 251 | 163 | 105 | | 4 | | 18 | 51 | | 25 | 33 | 29 | 5 | 43 | 87 | 16 | 27 | 7 | 341 |
| 1 | 252 | 110 | 84 | | 4 | | | 5 | | 5 | 3 | | | | 41 | | | 9 | 63 |
| 1 | 253 | 107 | 86 | 25 | 4 | | | 5 | | 5 | | 3 | 15 | | 11 | 21 | 20 | 11 | 91 |
| 1 | 254 | 158 | 100 | 8 | 4 | | 37 | 20 | | 8 | 53 | 19 | 15 | 27 | 80 | 64 | 31 | 11 | 365 |
| 1 | 255 | 200 | 104 | 5 | 3 | 7 | 34 | 87 | | 8 | 27 | 39 | | 37 | 176 | 128 | 37 | 25 | 605 |
| 1 | 256 | 174 | 104 | | 4 | | 28 | 52 | | 25 | 21 | 11 | 3 | 91 | 94 | 21 | | 22 | 368 |
| 1 | 257 | 221 | 111 | 4 | 3 | | 36 | 74 | | | 78 | 55 | 3 | 43 | 273 | 86 | 63 | 48 | 759 |
| 1 | 258 | 281 | 130 | | 4 | 13 | 83 | 96 | | 48 | 60 | 30 | 49 | 11 | 283 | 411 | 148 | 140 | 1372 |
| 1 | 259 | 166 | 104 | | 4 | | 5 | 34 | | | 66 | 10 | | 32 | 112 | 40 | 19 | | 318 |
| 1 | 260 | 211 | 124 | 5 | 4 | | 71 | 61 | | | 59 | 39 | 5 | 144 | 203 | 145 | 66 | 8 | 801 |
| 1 | 261 | 199 | 116 | 9 | 1 | | | 32 | | 8 | 5 | 50 | 5 | 37 | 213 | 126 | 70 | 69 | 615 |
| 1 | 262 | 244 | 136 | 2 | 4 | | 80 | 121 | | 11 | 105 | 17 | | 130 | 346 | 293 | 56 | | 1159 |
| 1 | 263 | 182 | 120 | 2 | 1 | | | 26 | | | 38 | 21 | 4 | 27 | 341 | 118 | 46 | 11 | 632 |
| 1 | 264 | 190 | 133 | 6 | 2 | | 31 | 32 | | 11 | 64 | 40 | 5 | 21 | 217 | 107 | 43 | 119 | 690 |
| 1 | 265 | 168 | 119 | 6 | 3 | | 12 | 24 | | 11 | 31 | 16 | 5 | 78 | 208 | 79 | 53 | 7 | 524 |
| 1 | 266 | 216 | 128 | 7 | 4 | 11 | 49 | 90 | | 13 | 36 | 8 | | 80 | 227 | 118 | 59 | 8 | 701 |
| 1 | 267 | 226 | 126 | 13 | 2 | | | 74 | | 33 | 39 | 16 | 11 | 16 | 289 | 41 | 135 | 57 | 711 |
| 1 | 268 | 132 | 100 | | 3 | | | | | 7 | 8 | 22 | 14 | | 54 | 12 | 55 | 49 | 221 |
| 1 | 269 | 169 | 109 | 5 | 2 | 19 | 36 | 58 | 10 | 28 | 66 | 11 | | 20 | 133 | 82 | 21 | | 484 |
| 1 | 270 | 179 | 119 | 3 | 4 | 26 | 35 | 65 | | 8 | 47 | 19 | | 80 | 124 | 11 | 78 | 11 | 504 |
| 1 | 271 | 184 | 111 | 10 | 3 | | 15 | 24 | | 8 | 23 | 34 | 6 | 21 | 105 | 63 | 139 | 126 | 566 |
| 1 | 273 | 177 | 117 | 6 | 4 | 27 | 43 | 40 | | | 40 | 10 | 12 | | 162 | 69 | | 64 | 467 |
| 1 | 275 | 188 | 117 | 4 | 4 | | 13 | 33 | | | 26 | 42 | | 54 | 80 | 21 | 69 | | 338 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | VOLUME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 8-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 1 | 276 | 147 | 110 | 14 | 4 | | | 7 | | | 45 | 8 | | 43 | 70 | 74 | 42 | 5 | 294 |
| 1 | 277 | 184 | 125 | 5 | 4 | | 7 | 72 | | 8 | 25 | 25 | | | 186 | 86 | 105 | 9 | 519 |
| 1 | 276 | 159 | 122 | 21 | 4 | | | 28 | | 5 | 10 | 20 | | | 141 | | 47 | 16 | 267 |
| 1 | 279 | 237 | 132 | 4 | 4 | 8 | 31 | 129 | | | 72 | 34 | 5 | 91 | 401 | 160 | 74 | 30 | 1035 |
| 1 | 280 | 123 | 107 | | 4 | | | 35 | | | 18 | 9 | | | 112 | 25 | 32 | | 231 |
| 1 | 281 | 278 | 135 | 6 | 4 | 51 | 120 | 104 | | | 134 | 34 | | 175 | 346 | 206 | 27 | 40 | 1237 |
| 1 | 282 | 147 | 115 | 4 | 4 | | | 28 | 8 | 8 | 34 | | 5 | 48 | 81 | 70 | 37 | | 319 |
| 1 | 283 | 247 | 127 | 18 | 1 | | 19 | 71 | | 13 | 32 | 25 | 27 | 16 | 139 | 131 | 115 | 174 | 762 |
| 1 | 284 | 189 | 126 | 5 | 3 | | 7 | 72 | | | 38 | 16 | | 27 | 311 | 61 | 80 | | 612 |
| 1 | 235 | 242 | 133 | 9 | 4 | | 8 | 27 | | 8 | 67 | 44 | 8 | 21 | 366 | 232 | 150 | 79 | 1010 |
| 1 | 301 | 185 | 107 | 7 | 3 | | 14 | 39 | | 5 | 39 | 24 | 3 | | 150 | 91 | 64 | 14 | 443 |
| 1 | 302 | 219 | 108 | 5 | 1 | | | 8 | | 19 | 41 | 14 | 11 | | 187 | 213 | 55 | 21 | 569 |
| 1 | 303 | 143 | 88 | 13 | 3 | | 11 | | | 10 | 17 | 10 | 5 | 16 | 32 | 64 | 16 | 23 | 204 |
| 1 | 304 | 204 | 114 | 3 | 4 | | 21 | 74 | | 8 | 22 | 6 | 7 | 107 | 140 | 99 | 105 | | 589 |
| 1 | 305 | 166 | 105 | 6 | 3 | | 24 | 23 | | | 26 | 8 | | 64 | 91 | 64 | 44 | 7 | 351 |
| 1 | 307 | 113 | 98 | | 3 | | | 5 | | 5 | 22 | | | | 96 | 11 | | 22 | 161 |
| 1 | 308 | 325 | 120 | 9 | 4 | | | 20 | | | 39 | 32 | 50 | 27 | 144 | 175 | 404 | 738 | 1629 |
| 1 | 309 | 152 | 81 | | 3 | | | 17 | | 15 | 12 | 14 | 5 | | 96 | 17 | 43 | 9 | 228 |
| 1 | 310 | 171 | 101 | 4 | 4 | | | 53 | | 19 | 27 | 5 | | 16 | 145 | 64 | 56 | 8 | 393 |
| 1 | 312 | 156 | 103 | 9 | 1 | | | 15 | | | 31 | | 4 | 27 | 151 | 27 | 9 | | 264 |
| 1 | 313 | 190 | 106 | 6 | 2 | | | 4 | | 16 | 50 | 11 | 9 | 32 | 182 | 41 | 69 | 23 | 437 |
| 1 | 314 | 163 | 98 | 4 | 3 | | | 14 | | 11 | 33 | 24 | | 37 | 100 | 60 | 54 | | 333 |

| | | | | | | VOLUME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 2 | 1 | 268 | 114 | 23 | 3 | | 122 | 71 | | 14 | 57 | 107 | 35 | 27 | 91 | 163 | 196 | 45 | 928 |
| 2 | 2 | 217 | 123 | 37 | 3 | | 43 | 69 | | 19 | 97 | 49 | 17 | 42 | 176 | 91 | 21 | | 624 |
| 2 | 4 | 362 | 136 | 41 | 3 | | 363 | 173 | | 30 | 358 | 213 | 105 | 96 | 135 | 147 | 472 | 179 | 2271 |
| 2 | 5 | 300 | 123 | 28 | 2 | | 170 | 118 | | | 199 | 140 | 96 | | 23 | 215 | 217 | 31 | 1209 |
| 2 | 6 | 279 | 126 | 23 | 2 | | 219 | 86 | | 41 | 84 | 67 | 3 | 80 | 204 | 178 | 17 | 27 | 1006 |
| 2 | 7 | 182 | 83 | 20 | 4 | | 35 | 6 | | 12 | 32 | 31 | 7 | | 99 | 16 | 20 | | 258 |
| 2 | 8 | 209 | 99 | 50 | 3 | | | | | 5 | 33 | 6 | 9 | | 35 | | 12 | 14 | 114 |
| 2 | 9 | 298 | 140 | 18 | 4 | | 87 | 61 | | 16 | 101 | 76 | 34 | | 298 | 283 | 52 | | 1008 |
| 2 | 10 | 281 | 123 | 10 | 4 | | 84 | 44 | | | 110 | 138 | 8 | | 42 | 212 | 385 | 16 | 1039 |
| 2 | 11 | 276 | 120 | 22 | 1 | | 130 | 120 | | 17 | 123 | 74 | | 21 | 96 | 320 | 48 | | 949 |
| 2 | 12 | 190 | 105 | 29 | | | 14 | 36 | | 8 | 36 | 19 | | 13 | 110 | 88 | 59 | 27 | 410 |
| 2 | 13 | 325 | 134 | 19 | 4 | | 321 | 163 | | | 98 | 191 | 52 | 32 | 229 | 328 | 193 | 87 | 1694 |
| 2 | 14 | 198 | 111 | 22 | 3 | | 40 | 30 | | | 29 | 44 | 32 | 12 | 72 | 122 | 11 | 14 | 406 |
| 2 | 15 | 289 | 134 | 7 | 4 | | 167 | 97 | | 43 | 104 | 128 | 16 | | 300 | 252 | 64 | | 1171 |
| 2 | 16 | 303 | 134 | 20 | 2 | | 111 | 97 | | 2 | 253 | 217 | 71 | 21 | 89 | 372 | 275 | | 1508 |
| 2 | 17 | 416 | 142 | 18 | 3 | | 812 | 167 | | 38 | 285 | 202 | 63 | 42 | 236 | 250 | 301 | 119 | 2515 |
| 2 | 18 | 301 | 124 | 20 | 3 | | 200 | 117 | | 8 | 177 | 105 | 26 | 32 | 50 | 474 | 279 | 71 | 1539 |
| 2 | 19 | 235 | 106 | 18 | 1 | | 18 | 20 | | 3 | 73 | 77 | 11 | 27 | 277 | 185 | 59 | | 750 |
| 2 | 20 | 270 | 134 | 22 | 4 | | 227 | 142 | | 21 | 50 | 134 | 52 | | 156 | 161 | 258 | 58 | 1259 |
| 2 | 21 | 313 | 144 | 13 | 2 | | 54 | 82 | | 13 | 273 | 174 | 2 | 66 | 388 | 291 | 247 | 27 | 1617 |
| 2 | 22 | 308 | 148 | 14 | 4 | | 178 | 47 | | 48 | 195 | 143 | 34 | | 275 | 310 | 32 | 17 | 1279 |
| 2 | 23 | 264 | 140 | 12 | 4 | | 144 | 186 | | 52 | 145 | 157 | 30 | | 237 | 121 | 84 | | 1156 |
| 2 | 24 | 260 | 120 | 74 | 3 | | 12 | 17 | | | 36 | 74 | 16 | | | | | | 155 |
| 2 | 25 | 252 | 130 | 5 | 2 | | 101 | 78 | | 53 | 167 | 50 | | 20 | 81 | 149 | 35 | 43 | 777 |
| 2 | 26 | 178 | 113 | | 4 | | 26 | 34 | | 31 | 48 | 3 | | 48 | 131 | | 11 | | 332 |
| 2 | 27 | 118 | 103 | | 1 | | 2 | | | 15 | 15 | 3 | | 16 | 23 | 38 | 16 | | 128 |
| 2 | 29 | 282 | 130 | 56 | 2 | | 98 | 38 | | 14 | 118 | 66 | 18 | | | | | | 352 |
| 2 | 30 | 180 | 99 | 92 | | | | | | 9 | 5 | | | | | 11 | 9 | | 34 |
| 2 | 31 | 259 | 134 | 21 | 4 | | 285 | 195 | | 25 | 172 | 56 | | 16 | 227 | 48 | | | 1024 |
| 2 | 32 | 196 | 124 | 6 | 3 | | 25 | 34 | | 3 | 61 | | | 160 | 176 | 70 | 21 | | 550 |
| 2 | 37 | 208 | 124 | 12 | 4 | | 99 | 31 | | 34 | 42 | 43 | 12 | 33 | 201 | 75 | 33 | | 603 |
| 2 | 38 | 241 | 127 | 19 | | | 19 | 22 | | 24 | 52 | 43 | 6 | 82 | 265 | 70 | | 7 | 590 |
| 2 | 39 | 178 | 111 | 5 | 2 | | 7 | 13 | | 20 | 27 | 26 | 28 | | 122 | 16 | 80 | | 339 |
| 2 | 40 | 289 | 140 | 10 | 2 | | 160 | 14 | | 49 | 174 | 80 | 12 | | 240 | 285 | 95 | 11 | 1120 |
| 2 | 41 | 378 | 150 | 27 | 3 | | 174 | 142 | | 9 | 161 | 250 | 48 | 28 | 273 | 371 | 204 | 43 | 1703 |
| 2 | 44 | 345 | 135 | 22 | 4 | | 95 | 60 | | 39 | 242 | 259 | 65 | | 84 | 196 | 486 | 53 | 1579 |
| 2 | 45 | 308 | 129 | 14 | 2 | | 219 | 101 | | 30 | 151 | 77 | 45 | | 178 | 111 | 118 | 166 | 1196 |
| 2 | 46 | 381 | 133 | 16 | 3 | | 41 | 166 | | 32 | 276 | 296 | 69 | 32 | 84 | 547 | 677 | 176 | 2596 |
| 2 | 47 | 370 | 136 | 21 | 4 | | 155 | 126 | | 37 | 284 | 185 | 109 | | 77 | 278 | 386 | 84 | 1721 |
| 2 | 48 | 379 | 138 | 18 | 3 | | 138 | 132 | | 38 | 280 | 220 | 42 | | 82 | 531 | 691 | 78 | 2230 |

| | | | | | | V O L U M E | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 2 | 49 | 185 | 104 | 48 | 2 | | 17 | 23 | | | 39 | 18 | | | 27 | 74 | 11 | 6 | 215 |
| 2 | 50 | 347 | 146 | 28 | 4 | | 173 | 156 | | 22 | 180 | 177 | 59 | 80 | 279 | 473 | 305 | 160 | 2064 |
| 2 | 51 | 333 | 144 | 28 | 4 | | 91 | 87 | | 41 | 233 | 227 | 59 | | 138 | 205 | 460 | 211 | 1752 |
| 2 | 52 | 357 | 144 | 38 | 4 | | 39 | 76 | | 9 | 96 | 179 | 39 | 109 | 189 | 284 | 236 | 30 | 1286 |
| 2 | 53 | 258 | 124 | 7 | 4 | | 100 | 63 | | 18 | 91 | 43 | 4 | 47 | 225 | 252 | 48 | 26 | 917 |
| 2 | 54 | 359 | 118 | 53 | 2 | | 178 | 147 | | 25 | 151 | 288 | 85 | | 56 | 61 | 205 | 149 | 1345 |
| 2 | 55 | 359 | 130 | 26 | 3 | | 250 | 125 | | 102 | 263 | 293 | 103 | 36 | 36 | 290 | 212 | 96 | 1806 |
| 2 | 56 | 229 | 130 | 14 | 3 | | 93 | 78 | | 5 | 164 | 71 | 30 | | 51 | 180 | 126 | 75 | 873 |
| 2 | 58 | 401 | 149 | 49 | 2 | | 183 | 229 | | 45 | 241 | 430 | 278 | | 36 | 89 | 120 | 140 | 1791 |
| 2 | 59 | 265 | 127 | 12 | | | 5 | 14 | | 2 | 46 | 157 | 48 | 10 | 160 | 160 | 186 | 53 | 841 |
| 2 | 60 | 115 | 72 | | 2 | | | | | 16 | 3 | 5 | | | 11 | 44 | | | 79 |
| 2 | 61 | 376 | 147 | 62 | 3 | | 240 | 103 | | | 87 | 262 | 222 | | 8 | 24 | 85 | 86 | 1117 |
| 2 | 62 | 355 | 122 | 31 | 3 | | 60 | 50 | | 22 | 188 | 143 | 60 | | 36 | 190 | 442 | 145 | 1336 |
| 2 | 63 | 244 | 121 | 37 | 2 | | 23 | 41 | | 46 | 159 | 12 | | 27 | 67 | 67 | 48 | | 490 |
| 2 | 64 | 286 | 113 | 9 | 2 | | 46 | 53 | | 20 | 59 | 74 | 50 | 27 | 188 | 218 | 38 | 5 | 778 |
| 2 | 65 | 142 | 95 | | 1 | | 3 | | | 12 | 24 | 12 | | 21 | 96 | 51 | 32 | | 251 |
| 2 | 66 | 242 | 144 | 4 | | | 13 | 47 | | 21 | 118 | 42 | | 107 | 260 | 194 | 69 | | 871 |
| 2 | 67 | 159 | 100 | | | | 4 | | | 12 | 32 | 10 | 10 | | 155 | 70 | 16 | | 309 |
| 2 | 69 | 255 | 116 | 14 | | | 3 | 18 | | | 84 | 81 | 18 | | 172 | 306 | 100 | | 782 |
| 2 | 70 | 179 | 102 | 21 | 3 | | 8 | 16 | | 11 | 30 | 9 | 3 | 150 | 111 | 42 | 30 | | 410 |
| 2 | 71 | 240 | 116 | 3 | 4 | | 49 | 58 | | 35 | 123 | 44 | | 67 | 280 | 143 | 107 | 16 | 922 |
| 2 | 72 | 220 | 125 | 1 | 2 | | 13 | 32 | | 5 | 102 | 56 | | 74 | 214 | 209 | 81 | 27 | 813 |
| 2 | 73 | 329 | 138 | 16 | | | 37 | 61 | | 9 | 218 | 196 | 73 | 43 | 196 | 553 | 212 | 28 | 1625 |
| 2 | 74 | 265 | 118 | 15 | 2 | | 6 | 25 | | | 88 | 78 | 10 | | 19 | 257 | 126 | 32 | 641 |
| 2 | 75 | 425 | 148 | 24 | 3 | | 73 | 134 | | | 451 | 634 | 91 | 14 | 137 | 235 | 750 | 248 | 2767 |
| 2 | 76 | 280 | 113 | 9 | | | 11 | 2 | | 7 | 67 | 88 | | | 347 | 560 | 183 | 42 | 1307 |
| 2 | 77 | 306 | 134 | 9 | | | 78 | 79 | | 14 | 180 | 184 | 18 | | 152 | 637 | 376 | 59 | 1777 |
| 2 | 78 | 225 | 130 | 12 | 1 | | 13 | 12 | | 27 | 127 | 102 | 7 | | 256 | 258 | | | 799 |
| 2 | 79 | 224 | 118 | 27 | | | 4 | | | | 33 | 8 | | 16 | 124 | 243 | 107 | 23 | 558 |
| 2 | 80 | 178 | 104 | 4 | 2 | | | 8 | | 5 | 40 | 27 | 18 | | 49 | 106 | 21 | 72 | 346 |
| 2 | 81 | 201 | 120 | 12 | 2 | | 53 | 26 | | 9 | 44 | 29 | 53 | 96 | 137 | 88 | | 60 | 595 |
| 2 | 83 | 191 | 113 | 14 | | | 25 | 22 | | 7 | 53 | | | 43 | 269 | 137 | 43 | 21 | 620 |
| 2 | 84 | 169 | 114 | | | | 7 | 8 | | 50 | 72 | 22 | 12 | 21 | 69 | 90 | | | 351 |
| 2 | 85 | 421 | 134 | 47 | 2 | | 188 | 99 | | 14 | 195 | 301 | 181 | | 55 | | 107 | 319 | 1459 |
| 2 | 86 | 134 | 86 | 8 | | | 9 | | | 5 | 8 | 5 | | | 28 | 8 | 37 | 16 | 115 |
| 2 | 87 | 271 | 112 | 23 | | | 25 | 50 | | 8 | 100 | 58 | 4 | 56 | 163 | 163 | 198 | 88 | 913 |
| 2 | 88 | 166 | 73 | 81 | 4 | | 5 | 5 | | | 3 | 5 | | | 28 | 11 | 12 | | 69 |
| 2 | 89 | 314 | 123 | 29 | | | 25 | | | | 54 | 58 | 123 | | 189 | 243 | 107 | 64 | 863 |
| 2 | 90 | 245 | 126 | 19 | 1 | | 20 | 34 | | 36 | 121 | 107 | 43 | 32 | 60 | 140 | 249 | 121 | 1003 |
| 2 | 93 | 251 | 118 | 14 | 1 | | 25 | 47 | | 5 | 108 | 59 | 46 | | 103 | 263 | 105 | | 761 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | V O L U M E | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 2 | 94 | 272 | 106 | 80 | 2 | | 5 | | | 3 | 15 | 75 | 32 | | | | | | 130 |
| 2 | 95 | 145 | 92 | 18 | 3 | | | 6 | | | 20 | 21 | 14 | 16 | 24 | | 32 | | 133 |
| 2 | 96 | 295 | 132 | 7 | 4 | | 51 | 58 | | | 115 | 107 | 62 | 80 | 183 | 296 | 235 | | 1187 |
| 2 | 98 | 169 | 104 | 11 | 4 | | 23 | 19 | | 29 | 31 | 17 | | | 54 | 25 | 27 | 39 | 264 |
| 2 | 99 | 139 | 96 | | 3 | | 2 | | | 22 | 44 | 3 | 3 | | 14 | 52 | 15 | | 155 |
| 2 | 102 | 229 | 136 | 9 | 4 | | 108 | 85 | | 25 | 157 | 29 | 29 | 35 | 178 | 158 | 69 | 16 | 889 |
| 2 | 103 | 169 | 120 | 15 | 2 | | 15 | 21 | | 14 | 36 | 13 | 18 | 41 | 155 | 9 | | | 322 |
| 2 | 104 | 278 | 132 | 29 | 1 | | 40 | 60 | | | 63 | 79 | 100 | | 115 | 322 | 211 | 28 | 1018 |
| 2 | 105 | 287 | 128 | 21 | 2 | | 35 | 34 | | 33 | 148 | 115 | 12 | 27 | 114 | 325 | 68 | | 911 |
| 2 | 106 | 160 | 102 | | 4 | | 18 | 3 | | | 27 | 22 | 7 | 53 | 72 | 9 | | | 211 |
| 2 | 109 | 272 | 112 | 28 | 2 | | 12 | 41 | | 8 | 78 | 51 | 23 | | 128 | 76 | 170 | 55 | 642 |
| 2 | 110 | 132 | 110 | 12 | 3 | | 13 | | | 49 | 62 | 76 | 15 | 21 | 105 | | | | 341 |
| 2 | 111 | 192 | 91 | | | | | 6 | | 11 | 44 | 7 | 5 | 16 | 175 | 21 | 16 | | 301 |
| 2 | 112 | 212 | 104 | 8 | 2 | | 4 | 20 | | 23 | 28 | 3 | | | 173 | 142 | 16 | 4 | 413 |
| 2 | 113 | 150 | 89 | 14 | 3 | | 21 | | | 28 | 44 | 4 | | | 70 | 44 | | | 211 |
| 2 | 115 | 185 | 107 | 12 | 3 | | 7 | 36 | | 38 | 53 | 21 | | 21 | 42 | 89 | 103 | | 410 |
| 2 | 117 | 203 | 122 | 11 | 3 | | 130 | 81 | | 24 | 61 | 77 | 7 | | 159 | 137 | 8 | | 684 |
| 2 | 118 | 217 | 115 | 19 | 3 | | 49 | 58 | | 19 | 44 | 55 | | 21 | 110 | 60 | 31 | 40 | 487 |
| 2 | 119 | 314 | 118 | 13 | 2 | | 229 | 212 | | 46 | 89 | 71 | 23 | | 148 | 108 | 115 | 66 | 1107 |
| 2 | 120 | 178 | 114 | 8 | 3 | | 12 | 38 | | 20 | 33 | 13 | | 37 | 254 | 28 | 18 | | 453 |
| 2 | 122 | 209 | 109 | 8 | 3 | | 7 | 18 | | 19 | 52 | 24 | 4 | 16 | 103 | 132 | 53 | 16 | 444 |
| 2 | 123 | 347 | 128 | 51 | 3 | | 125 | 163 | | 21 | 142 | 254 | 31 | | 77 | 188 | 199 | 85 | 1285 |
| 2 | 124 | 217 | 122 | 7 | 3 | | 51 | 66 | | 32 | 104 | 51 | | 55 | 93 | 123 | | | 575 |
| 2 | 125 | 106 | 50 | | 2 | | 3 | 3 | | 5 | 10 | 18 | 3 | | 21 | 7 | | 5 | 75 |
| 2 | 127 | 137 | 74 | 27 | 3 | | 9 | 5 | | 27 | 5 | 7 | | | 16 | 33 | 16 | | 118 |
| 2 | 128 | 349 | 134 | 61 | 4 | | 68 | 36 | | 12 | 65 | 85 | 15 | | 16 | 112 | 164 | 120 | 693 |
| 2 | 129 | 205 | 104 | 11 | 1 | | 6 | 38 | | 35 | 30 | 16 | | 21 | 58 | 80 | 86 | | 370 |
| 2 | 131 | 136 | 72 | 18 | 3 | | 3 | 12 | | 32 | 26 | 15 | | | | 7 | | | 95 |
| 2 | 132 | 192 | 94 | 3 | 3 | | 34 | 34 | | 36 | 29 | | 4 | | 220 | 21 | | | 378 |
| 2 | 133 | 116 | 59 | 29 | 3 | | 4 | | | 3 | 7 | 5 | | | | | | | 19 |
| 2 | 134 | 223 | 117 | 5 | 4 | | 70 | 77 | | 55 | 86 | 17 | | 21 | 147 | 200 | 63 | | 736 |
| 2 | 135 | 194 | 99 | 18 | 3 | | 61 | 31 | | 56 | 30 | | 2 | | 86 | 37 | | | 303 |
| 2 | 136 | 368 | 131 | 58 | 3 | | 202 | 51 | | 14 | 63 | 277 | 29 | | 23 | 117 | 193 | 51 | 1020 |
| 2 | 137 | 286 | 122 | 19 | 4 | | 277 | 129 | | 77 | 136 | 113 | 29 | | 27 | 157 | 126 | 4 | 1075 |
| 2 | 138 | 170 | 98 | 12 | 2 | | | 15 | | 40 | 66 | 11 | | | 90 | | 29 | | 251 |
| 2 | 139 | 295 | 126 | 36 | 4 | | 188 | 132 | | 53 | 219 | 229 | 255 | 16 | 30 | 110 | 89 | | 1321 |
| 2 | 140 | 340 | 124 | 15 | 3 | | 142 | 99 | | 11 | 143 | 143 | 38 | 46 | 265 | 330 | 115 | 13 | 1345 |
| 2 | 141 | 298 | 126 | 31 | 2 | | 182 | 154 | | | 137 | 32 | 20 | | 107 | 221 | 98 | 129 | 1080 |
| 2 | 142 | 305 | 126 | 16 | 4 | | 236 | 158 | | 24 | 110 | 47 | 9 | | 178 | 185 | 103 | 20 | 1070 |
| 2 | 143 | 234 | 104 | 34 | 4 | | 32 | 18 | | 10 | 20 | 60 | | 14 | 165 | 23 | 14 | 14 | 370 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | VOLUME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 8-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
| 2 | 144 | 297 | 123 | 27 | 2 | | 243 | 74 | | 55 | 86 | 54 | 23 | | 147 | 90 | 62 | | 834 |
| 2 | 145 | 189 | 113 | 11 | 1 | | 10 | 17 | | 5 | 64 | 22 | | 21 | 160 | 99 | 21 | | 419 |
| 2 | 146 | 156 | 94 | 5 | 3 | | | 8 | | 22 | 41 | 11 | 11 | | 61 | 28 | 44 | 19 | 245 |
| 2 | 147 | 131 | 89 | 14 | 2 | | 14 | 3 | | 27 | 77 | 13 | 6 | | 26 | | | | 166 |
| 2 | 148 | 164 | 95 | 30 | 2 | | 6 | | | 21 | 28 | 9 | 7 | | 57 | 38 | 11 | | 177 |
| 2 | 149 | 199 | 105 | 50 | 1 | | 25 | 15 | | 31 | 37 | 13 | | | 135 | 56 | 43 | | 355 |
| 2 | 150 | 194 | 102 | 23 | 3 | | 27 | 28 | | 7 | 30 | 20 | | 16 | 107 | 46 | 33 | | 314 |
| 2 | 151 | 175 | 80 | 29 | 1 | | 3 | | | 12 | 20 | 18 | 3 | | 64 | 13 | | | 133 |
| 2 | 152 | 126 | 83 | 33 | 1 | | | 5 | | 5 | 20 | | | | 20 | | 14 | | 64 |
| 2 | 154 | 182 | 107 | | 1 | | | 23 | | 2 | 77 | 32 | 11 | | 104 | 171 | 72 | 19 | 511 |
| 2 | 155 | 185 | 111 | | 4 | | 16 | 6 | | 39 | 35 | 10 | 8 | | 206 | 87 | 49 | 19 | 475 |
| 2 | 157 | 183 | 97 | 18 | 3 | | 12 | 12 | | 17 | 36 | 18 | 3 | 21 | 40 | 62 | | | 221 |
| 2 | 158 | 150 | 76 | 44 | 1 | | 5 | 12 | | 5 | 21 | 3 | | | | | | | 46 |
| 2 | 159 | 211 | 117 | 27 | 1 | | 22 | 35 | | 32 | 59 | 46 | 14 | | 111 | 89 | | 4 | 412 |
| 2 | 160 | 134 | 73 | 50 | 2 | | 3 | 5 | | 5 | 7 | 12 | | | 18 | 7 | | | 57 |
| 2 | 161 | 194 | 103 | 8 | 2 | | 5 | | | 8 | 14 | 12 | 5 | | 126 | 76 | 42 | 21 | 309 |
| 2 | 163 | 160 | 108 | 11 | 4 | | 15 | 19 | | 41 | 26 | 28 | 3 | 35 | 128 | 48 | 123 | | 466 |
| 2 | 164 | 153 | 87 | 12 | 3 | | 7 | | | 36 | 18 | 13 | 5 | | 80 | 90 | | | 249 |
| 2 | 165 | 186 | 96 | 18 | 1 | | | 7 | | 5 | 33 | 31 | | | 149 | 51 | 99 | | 375 |
| 2 | 166 | 170 | 102 | 17 | 1 | | 4 | 8 | | 22 | 51 | 3 | 9 | 14 | 87 | 28 | 35 | 8 | 269 |
| 2 | 168 | 214 | 111 | 7 | 1 | | 41 | 7 | | 15 | 36 | 42 | 9 | 43 | 137 | 96 | 64 | 16 | 506 |
| 2 | 169 | 183 | 102 | 21 | 2 | | | 14 | | 21 | 56 | 23 | 7 | 28 | 177 | 105 | | | 431 |
| 2 | 170 | 235 | 116 | 13 | 3 | | 49 | 39 | | 31 | 55 | 48 | 18 | 23 | 169 | 218 | 4 | 11 | 665 |
| 2 | 174 | 192 | 113 | 10 | 2 | | 57 | 38 | | 26 | 22 | 12 | | 35 | 205 | 43 | 34 | | 472 |
| 2 | 175 | 196 | 111 | 5 | 2 | | 12 | 20 | | 8 | 56 | 4 | 8 | 47 | 249 | 132 | 22 | | 558 |
| 2 | 176 | 213 | 114 | 24 | 2 | | 17 | 21 | | 5 | 36 | 29 | | | 100 | 133 | 23 | | 364 |
| 2 | 178 | 156 | 85 | 37 | 2 | | 13 | 5 | | | 46 | 28 | | | 59 | | | | 151 |
| 2 | 179 | 259 | 113 | 12 | 2 | | 56 | 37 | | 43 | 116 | 28 | 3 | 50 | 259 | 84 | 16 | | 692 |
| 2 | 180 | 210 | 112 | 3 | 3 | | 37 | 19 | | 43 | 60 | 49 | | 42 | 83 | 65 | | | 398 |
| 2 | 181 | 232 | 120 | 5 | 3 | | 10 | 16 | | 61 | 140 | 137 | | | 190 | 182 | 21 | 12 | 769 |
| 2 | 182 | 205 | 120 | 10 | 4 | | 54 | 45 | | 42 | 72 | 3 | 4 | | 330 | 104 | 8 | 16 | 678 |
| 2 | 183 | 177 | 117 | 3 | 4 | | 24 | | | 42 | 39 | 12 | 5 | 21 | 117 | 131 | 5 | 32 | 428 |
| 2 | 184 | 193 | 116 | 3 | 4 | | 40 | 43 | | 39 | 74 | 35 | 3 | 16 | 121 | 36 | 36 | 16 | 459 |
| 2 | 185 | 253 | 123 | 12 | 4 | | 53 | 58 | | 23 | 147 | 42 | 12 | 27 | 194 | 273 | 49 | 5 | 883 |
| 2 | 186 | 212 | 118 | 7 | 3 | | | 45 | | 43 | 93 | 41 | 12 | | 193 | 82 | 74 | | 583 |
| 2 | 187 | 369 | 144 | 62 | | | 46 | 15 | | | 131 | 120 | 64 | 27 | 55 | 361 | 168 | 48 | 1035 |
| 2 | 188 | 215 | 115 | 2 | 4 | | 14 | 40 | | | 88 | 100 | | 80 | 230 | 86 | 7 | | 645 |
| 2 | 189 | 291 | 122 | 8 | 2 | | 36 | 25 | | 17 | 97 | 47 | 4 | 14 | 52 | 426 | 151 | 43 | 912 |
| 2 | 190 | 190 | 116 | 9 | 4 | | 9 | | | 23 | 45 | 24 | 5 | 21 | 194 | 46 | 16 | | 382 |
| 2 | 191 | 176 | 114 | 3 | 4 | | 39 | 38 | | 100 | 89 | 17 | | 14 | 89 | 16 | | | 401 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | VOLUME B-SEL | C-SEL | D-SEL | 1-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 192 | 194 | 124 | 5 | 4 | | 35 | 72 | | 81 | 40 | 34 | 5 | 21 | 162 | 7 | | 40 | 497 |
| 2 | 193 | 184 | 104 | 7 | 3 | | 30 | 35 | | 54 | 41 | 11 | 2 | 21 | 78 | 24 | 7 | | 303 |
| 2 | 195 | 320 | 132 | 16 | 4 | | 98 | 98 | | 20 | 247 | 38 | 2 | 60 | 311 | 235 | 410 | 30 | 1549 |
| 2 | 196 | 351 | 136 | 21 | 1 | | 8 | 12 | | 6 | 229 | 176 | 50 | 14 | 133 | 434 | 503 | 174 | 1739 |
| 2 | 197 | 285 | 133 | 17 | 1 | | 53 | 136 | | 48 | 146 | 146 | 9 | 64 | 300 | 191 | 104 | | 1197 |
| 2 | 198 | 233 | 121 | 13 | 3 | | 74 | 71 | | 35 | 132 | 49 | 11 | 70 | 156 | 144 | 58 | | 800 |
| 2 | 199 | 132 | 84 | 45 | 1 | | | 2 | | 8 | 21 | | 5 | 28 | | | 8 | | 72 |
| 2 | 200 | 118 | 82 | | 2 | | | | | | 14 | | | 16 | 16 | 7 | | | 53 |
| 2 | 201 | 225 | 122 | 6 | 3 | | 96 | 99 | | 108 | 160 | 24 | | 53 | 53 | 120 | 43 | | 756 |
| 2 | 202 | 288 | 137 | 14 | 4 | | 268 | 86 | | 94 | 149 | 140 | 11 | 43 | 138 | 311 | 19 | | 1259 |
| 2 | 203 | 261 | 117 | 10 | 3 | | 185 | 104 | | 16 | 140 | 122 | 3 | 16 | 270 | 201 | 21 | | 1078 |
| 2 | 204 | 287 | 121 | 18 | 4 | | 131 | 73 | | 13 | 259 | 180 | 47 | | 27 | 226 | 164 | 14 | 1134 |
| 2 | 205 | 202 | 107 | 19 | 4 | | 61 | 11 | | 42 | 35 | 4 | | 14 | 183 | 68 | | | 418 |
| 2 | 206 | 311 | 124 | 28 | 2 | | 112 | 173 | | 32 | 202 | 125 | 60 | | 212 | 575 | 96 | 21 | 1608 |
| 2 | 207 | 275 | 117 | 12 | 3 | | 40 | 84 | | 48 | 153 | 125 | 2 | 27 | 262 | 396 | 149 | 53 | 1339 |
| 2 | 209 | 282 | 126 | 20 | 3 | | 27 | 49 | | 16 | 198 | 142 | 20 | | 20 | 168 | 449 | 95 | 1184 |
| 2 | 210 | 341 | 129 | 18 | 4 | | 172 | 120 | | 19 | 189 | 102 | 130 | | 5 | 348 | 429 | 342 | 1855 |
| 2 | 211 | 210 | 102 | 18 | 4 | | 29 | 21 | | | 49 | 41 | | | 82 | 57 | 29 | 21 | 329 |
| 2 | 212 | 217 | 100 | 15 | 3 | | 19 | | | 6 | 11 | 50 | 9 | | 155 | 30 | | | 280 |
| 2 | 213 | 145 | 99 | 15 | 3 | | 8 | 23 | | 43 | 58 | 20 | | | | 16 | | | 168 |
| 2 | 214 | 129 | 97 | 14 | 2 | | 3 | 16 | | 20 | 43 | 8 | 2 | 32 | | 23 | 11 | | 158 |
| 2 | 215 | 320 | 124 | 25 | 4 | | 231 | 124 | | 50 | 116 | 233 | 78 | | 88 | 264 | 164 | | 1348 |
| 2 | 216 | 171 | 103 | 3 | 3 | | 26 | 6 | | 8 | 31 | 35 | | 16 | 90 | 54 | | 7 | 273 |
| 2 | 217 | 206 | 95 | 23 | 4 | | 56 | 28 | | 26 | 35 | 22 | 5 | 96 | 101 | | | | 369 |
| 2 | 218 | 390 | 146 | 42 | 1 | | 60 | 80 | | 16 | 162 | 237 | 96 | | 64 | 230 | 290 | 217 | 1452 |
| 2 | 219 | 339 | 140 | 34 | 1 | | 92 | 43 | | 13 | 219 | 181 | 37 | | 252 | 480 | 113 | 75 | 1505 |
| 2 | 220 | 262 | 129 | 12 | 3 | | 31 | 57 | | 39 | 36 | 60 | | 35 | 370 | 356 | 28 | | 1012 |
| 2 | 221 | 249 | 96 | 29 | 2 | | 21 | 18 | | | 31 | 75 | 10 | | 33 | 139 | 109 | | 436 |
| 2 | 222 | 375 | 129 | 40 | 2 | | 65 | 51 | | 3 | 107 | 246 | 164 | | 47 | 77 | 582 | 222 | 1564 |
| 2 | 223 | 308 | 127 | 30 | 4 | | 181 | 142 | | 25 | 108 | 56 | 5 | 32 | 334 | 161 | 64 | | 1108 |
| 2 | 224 | 266 | 120 | 23 | 4 | | 145 | 72 | | 23 | 92 | 101 | 22 | 27 | 96 | 178 | 37 | 11 | 804 |
| 2 | 225 | 223 | 114 | 11 | 4 | | 59 | 57 | | 46 | 34 | 22 | | 53 | 261 | 83 | 66 | 23 | 704 |
| 2 | 226 | 420 | 134 | 39 | 2 | | 369 | 109 | | 18 | 149 | 106 | 83 | 18 | 40 | 45 | 409 | 260 | 1606 |
| 2 | 227 | 299 | 124 | 19 | 4 | | 275 | 132 | | 50 | 152 | 48 | | 70 | 228 | 387 | 156 | | 1528 |
| 2 | 228 | 301 | 130 | 19 | 4 | | 161 | 70 | | 111 | 189 | 35 | 13 | 43 | 236 | 227 | 114 | | 1199 |
| 2 | 229 | 218 | 117 | 16 | 3 | | 168 | 53 | | 83 | 160 | 34 | 49 | 21 | 149 | 64 | | 4 | 785 |
| 2 | 230 | 204 | 110 | 22 | 3 | | 8 | 75 | | 26 | 60 | 21 | | | 122 | 70 | 16 | 53 | 451 |
| 2 | 231 | 254 | 126 | 19 | 4 | | 252 | 81 | | 24 | 187 | 48 | 14 | | 51 | 61 | 96 | 74 | 888 |
| 2 | 232 | 206 | 103 | 21 | 3 | | 40 | 26 | | | 36 | 37 | 5 | | 100 | 90 | 112 | 40 | 486 |
| 2 | 233 | 210 | 100 | 16 | 2 | | 11 | 21 | | 60 | 96 | 2 | | | 91 | 106 | 29 | 5 | 421 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | VOLUME B-SEL | C-SEL | D-SEL | I-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 234 | 290 | 120 | 24 | 1 | | 126 | 112 | | 19 | 96 | 66 | 11 | 42 | 226 | 170 | 56 | | 924 |
| 2 | 235 | 310 | 133 | 7 | 4 | | 212 | 68 | | 59 | 144 | 78 | 4 | 21 | 249 | 202 | 150 | 11 | 1198 |
| 2 | 236 | 174 | 120 | 13 | 3 | | 61 | 51 | | 13 | 25 | 39 | | 16 | 214 | | 8 | | 427 |
| 2 | 237 | 239 | 114 | 17 | 1 | | 41 | 57 | | 3 | 75 | 6 | 15 | 27 | 207 | 99 | 57 | | 587 |
| 2 | 239 | 309 | 132 | 6 | 3 | | 271 | 161 | | 57 | 141 | 111 | 16 | | 145 | 358 | 75 | | 1335 |
| 2 | 240 | 271 | 130 | 15 | 4 | | 128 | 73 | | 13 | 119 | 106 | | 64 | 330 | 274 | | | 1107 |
| 2 | 241 | 152 | 73 | 28 | 1 | | | 7 | | | 58 | 23 | | | 59 | 11 | 14 | | 172 |
| 2 | 242 | 198 | 119 | 5 | 4 | | 40 | 19 | | 49 | 58 | 2 | 5 | 32 | 187 | 53 | | | 445 |
| 2 | 243 | 215 | 124 | 7 | 4 | | 117 | 98 | | 29 | 105 | 93 | | 23 | 199 | 147 | 96 | 4 | 911 |
| 2 | 244 | 264 | 114 | 4 | 4 | | 40 | 88 | | 46 | 180 | 59 | | 21 | 178 | 127 | 5 | | 744 |
| 2 | 245 | 186 | 117 | 12 | 4 | | 33 | 15 | | 8 | 97 | 25 | 2 | 16 | 177 | 16 | 27 | | 416 |
| 2 | 246 | 412 | 144 | 64 | 3 | | 100 | 118 | | 25 | 226 | 467 | 155 | | | 62 | 174 | 88 | 1415 |
| 2 | 247 | 137 | 110 | 4 | 4 | | 15 | 17 | | 68 | 35 | 7 | 11 | | 92 | | | | 245 |
| 2 | 248 | 175 | 110 | 5 | 4 | | 79 | 41 | | 42 | 63 | 5 | | 21 | 79 | 21 | | 16 | 367 |
| 2 | 249 | 320 | 143 | 13 | 3 | | 214 | 134 | | 41 | 180 | 150 | 32 | 28 | 438 | 471 | 161 | 53 | 1902 |
| 2 | 250 | 216 | 126 | 11 | 3 | | 72 | 38 | | 21 | 74 | 39 | | 48 | 274 | 129 | 14 | | 709 |
| 2 | 251 | 178 | 110 | 9 | 3 | | 20 | 16 | | 50 | 75 | 16 | | 21 | 112 | 40 | | | 350 |
| 2 | 252 | 323 | 128 | 11 | 4 | | 118 | 121 | | 82 | 284 | 171 | 55 | | 132 | 165 | 73 | 11 | 1212 |
| 2 | 254 | 288 | 118 | 25 | 4 | | 42 | 74 | | 19 | 180 | 168 | 52 | 74 | 73 | 163 | 336 | 45 | 1226 |
| 2 | 255 | 196 | 115 | 22 | 3 | | 21 | 15 | | 15 | 88 | 36 | 42 | | 16 | 45 | 64 | 21 | 363 |
| 2 | 256 | 183 | 116 | 13 | 3 | | 17 | 21 | | 75 | 58 | 12 | 5 | 21 | 156 | 64 | 18 | | 447 |
| 2 | 257 | 187 | 115 | 3 | 3 | | 52 | 68 | | 60 | 32 | | | 61 | 174 | 19 | | | 466 |
| 2 | 258 | 208 | 120 | 2 | 3 | | 41 | 62 | | 116 | 53 | | | | 162 | 95 | 21 | | 550 |
| 2 | 259 | 199 | 121 | 19 | 2 | | 37 | 26 | | 135 | 99 | 25 | | | 150 | 28 | 18 | | 518 |
| 2 | 261 | 279 | 117 | 19 | 4 | | 9 | 68 | | 11 | 116 | 67 | 9 | 50 | 80 | 244 | 43 | | 697 |
| 2 | 262 | 305 | 128 | 34 | 3 | | 18 | 38 | | | 167 | 153 | 58 | | 55 | 359 | 135 | | 983 |
| 2 | 263 | 113 | 83 | | 3 | | 14 | 3 | | 33 | 12 | | | | | | 11 | | 73 |
| 2 | 264 | 144 | 90 | | 1 | | | 8 | | 12 | 30 | 13 | | 37 | 76 | 48 | 15 | | 239 |
| 2 | 265 | 146 | 89 | 20 | 1 | | | 3 | | 17 | 31 | 5 | | 16 | 14 | 39 | 16 | | 141 |
| 2 | 266 | 138 | 77 | 33 | 1 | | | 3 | | 5 | 3 | 11 | | | | | 20 | | 42 |
| 2 | 267 | 131 | 72 | 8 | 2 | | 14 | 12 | | | 15 | | | | 22 | 60 | 7 | | 130 |
| 2 | 268 | 115 | 83 | 17 | 2 | | 5 | | | 10 | 20 | 4 | | | | 11 | | | 50 |
| 2 | 269 | 127 | 76 | 23 | 3 | | 7 | 4 | | 17 | 28 | 11 | | | 44 | | | | 111 |
| 2 | 270 | 109 | 67 | 17 | 3 | | | 6 | | 7 | 15 | 3 | | | | 14 | 5 | | 50 |
| 2 | 271 | 131 | 70 | 12 | 3 | | 5 | 5 | | 27 | 33 | 13 | | | | | | | 83 |
| 2 | 272 | 144 | 85 | 6 | 3 | | 8 | | | 7 | 15 | | | 16 | 69 | 11 | 44 | 7 | 177 |
| 2 | 273 | 182 | 83 | 3 | 4 | | 37 | 29 | | 41 | 41 | 19 | | 19 | 85 | 64 | | | 335 |
| 2 | 274 | 147 | 84 | 6 | 1 | | 31 | | | 17 | 29 | 10 | | 16 | 16 | 9 | 32 | | 160 |
| 2 | 275 | 134 | 78 | 18 | 3 | | 2 | 3 | | 23 | 27 | 7 | 3 | | 25 | 24 | | | 114 |
| 2 | 276 | 168 | 88 | 12 | 3 | | 32 | 29 | | 26 | 60 | 16 | | | 64 | 16 | 48 | 8 | 299 |

| STUDY | TREE | DBH | TOT HT | PCNT DEF | NLF16 | VOLUME A-SEL | C-SEL | D-SEL | I-COM | 2-COM | 3-COM | 4-COM | 5-COM | S-STR | CONST | STAND | UTIL | ECON | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 277 | 145 | 76 | | 3 | | 25 | 8 | | 52 | 3 | 14 | | | 8 | 14 | | | 124 |
| 2 | 278 | 114 | 79 | 12 | 2 | | 14 | 5 | | 27 | 33 | | 4 | | 14 | 7 | 9 | | 113 |
| 2 | 279 | 148 | 88 | | 3 | | 3 | 27 | | 26 | | 12 | | 16 | 69 | 32 | | | 185 |
| 2 | 280 | 125 | 87 | | 4 | | 21 | 5 | | 3 | 19 | | | 16 | 16 | 20 | | | 100 |

# *Appendix III*

## INSTRUCTIONS FOR MEASURING TREE CHARACTERISTICS

Instructions for measuring and recording the western larch tree characteristics used in the equations are shown below.

1. *Tree diameter (D)* is measured and recorded to the nearest 0.1 inch at 4-1/2 feet above ground on the uphill side on the tree.

2. *Tree height (H)* is total tree height measured from the ground on the uphill side of the tree and recorded to the nearest foot. This height includes a dead top if one exists and the projected height if the tree has a broken top.

3. *Number of limb-free and defect-free faces in the butt 16-foot log (NLDF16)*, where a face is one-fourth the circumference of the tree for the full 16-foot length of the butt 16-foot log (butt 16-foot log defined as the first 16.5 feet of the tree above normal stump height). Any limb or limb stub other than epicormic limbs removes a face. Any scalable defect removes the face in which the defect occurs. All size knot indicators are allowed. The variable is coded as 0-4 faces.

4. *Scalable defect (DEF)* is expressed as a percent of the gross cruise volume. The estimate includes deductions made from the gross cruise volume for visible abnormalities such as crook, conks, cankers, burls, and bumps. It also includes the estimated volume loss from unknown sources such as logging breakage and hidden or internal defects such as rot or pitch rings.

GPO 483-451

Plank, Marlin E., and Thomas A. Snellgrove.
1978. An equation for estimating the value and volume of western larch trees. USDA For. Serv. Res. Pap. PNW-231, 29 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This paper describes an equation for estimating the total sales value or the volume for western larch trees. The equation requires four easy-to-measure characteristics. Both the development and the application of the system are discussed.

KEYWORDS: Tree value, volume estimation, grading systems, western larch, *Larix occidentalis*.

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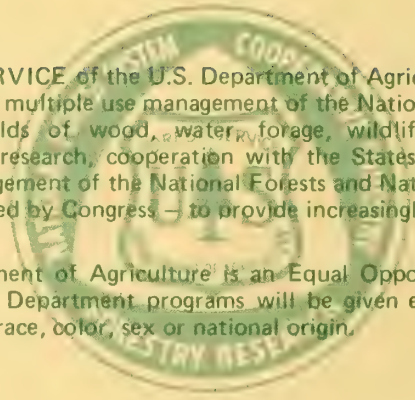
*Portland, Oregon 97208*



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USDA FOREST SERVICE RESEARCH PAPER PNW-232
1978

# HEIGHT GROWTH and SITE INDEX CURVES for MANAGED, EVEN-AGED STANDS of PONDEROSA PINE in the PACIFIC NORTHWEST

AMES W. BARRETT

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U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE PORTLAND, OREGON

*Metric Equivalents*

1 acre = 0.405 hectare

1 foot = 0.304 8 meter

# *Height Growth and Site Index Curves for Managed, Even-Aged Stands of Ponderosa Pine in the Pacific Northwest*

*Reference Abstract*

Barrett, James W.
1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-232, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This paper presents height growth and site index curves and equations for even-aged, managed stands of ponderosa pine east of the Cascade Range in Oregon and Washington where height growth has not been suppressed by high density or related factors.

KEYWORDS: Increment (height), site index -)stand height/age, measurement systems, stem analysis, ponderosa pine, *Pinus ponderosa*, Oregon (eastern), Washington (eastern).

*RESEARCH SUMMARY*

*Research Paper PNW-232*

*1978*

Height growth and site index curves and equations for even-aged managed stands of ponderosa pine (*Pinus ponderosa* Laws.) east of the Cascade Range in Oregon and Washington were derived from stem analysis data from 27 plots in Oregon and 3 plots in Washington.

Height growth curves estimate expected heights at different ages for stands of known site index. Site curves estimate site index of managed stands where breast height age and total height can be determined.

The curves provide valid estimates of site index and potential height growth for stands where height growth has not been retarded by high density or related factors. They do not represent the average of existing stands. The curves are most appropriate for use in constructing yield tables for managed, even-aged stands of ponderosa pine.

Curves are based on measure ments of the tallest tree in a 1/5-acre plot.

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## Introduction

This paper presents curves for estimating height growth and site index for even-aged, managed stands of ponderosa pine (*Pinus ponderosa* Laws.) east of the Cascade Range crest in Oregon and Washington. The curves represent growth potential under density conditions approximating those anticipated in managed stands of the future. The site curves are applicable to stands where relatively low density has permitted full height development so that the site estimate represents the full potential of the site. The data plots were deliberately chosen where stand development approximated densities believed desirable in managed stands, not merely the average of existing stands.1/ Therefore, the curves provide valid estimates of site index and potential height growth for stands where height growth has not been retarded by high density or related factors.

Impressive acreages of second-growth ponderosa pine east of the Cascade Range are being precommercially thinned to between 150 and 300 trees per acre. Additional acres are being planted at these densities. The thinning is being done to stimulate height and diameter growth so that we may grow usable trees in a much shorter time than if we allowed nature to follow its usual course of suppression, stagnation, insect attack, and then indiscriminate mortality. After thinning, the stand takes on attributes of what is commonly referred to as a managed stand or a stand that is being manipulated toward some predetermined goal. This goal is usually a "target" average stand diameter and height within some time frame.

The most "desirable density" is the density at which trees continue growing at the predetermined goal rate. As the stand grows older, relatively low density will be maintained by periodic thinnings to some basal area level or tree number--average diameter combination.

Height of the dominant or tallest portion of the stand is the one measure of growth found most independent of stand factors and, consequently, the most reliable for site evaluation (Lynch 1958). Generally speaking, we can conclude from the literature that height is not materially affected in stands that are not extremely overstocked or understocked (Spurr 1952). In the Pacific Northwest, however, Weaver (1947), Baker (1953), Mowat (1953), Lynch (1958) and Barrett (1973) have shown that dense stocking of ponderosa pine does reduce height growth.

Reducing the density below levels found in natural stands usually affects the height growth patterns shown by Meyer (1961) for "normal" stands. Fortunately, there seems to be a rather broad density range in ponderosa pine stands where density does not affect height growth of the larger trees in the stand. This range appears to fall within the density range now used by most ponderosa pine managers.

In this study I chose plots in stands that were 100 years or older and contained at least 60

1/ Summerfield, Edward R. Site index, height growth and productivity of ponderosa pine in eastern Washington. In preparation for publication by the State of Washington Department of Natural Resources.

trees per acre on the lower sites and no more than 200 trees per acre on the higher sites. Plots were selected in extensive, homogeneous, even-aged stands, not in clumps of even-aged trees. I did this to avoid the selection of exceptionally fast-growing trees and to incorporate the total stand effect into the site index and height growth system.

As time progresses, it will be necessary for managers to evaluate the productive capacity of these newly created stands. They will need a method of rating site and a method of predicting the course of stand height with age so that they may develop yield tables for second-growth ponderosa pine in the Pacific Northwest. This paper is a first step toward this goal. Therefore, these curves are most appropriately used in constructing yield tables for managed stands of ponderosa pine. The site curves will classify the growth potential of sample plots, and the height growth curves will express height development of even-aged stands attaining specified heights at index age.

When Meyer's (1961) site index curves are used in intensively managed, even-aged stands, it is difficult to select what Meyer refers to as "representative dominant and co-dominant trees." After trees are of merchantable size, all trees often appear to be dominants or codominants and selection can be subjective. In this study, I chose to eliminate this difficulty by dealing with only the tallest trees in the stand and densities likely to be found in *managed stands*.

## Data Collection

Thirty 1/5-acre circular plots were located throughout Oregon and parts of Washington (fig. 1). The plots had the following tree and stand characteristics:

1. The stand was pure ponderosa pine 95 to 180 years old at breast height and even-aged within 10 years.

2. Selective cutting or mortality had not removed the tallest tree within the age span of the existing stand.

3. The six tallest trees on the plot did not contain a group of more than four fine annual rings, which would indicate stress during a portion of the stand's life.

4. Trees were not infected with mistletoe.

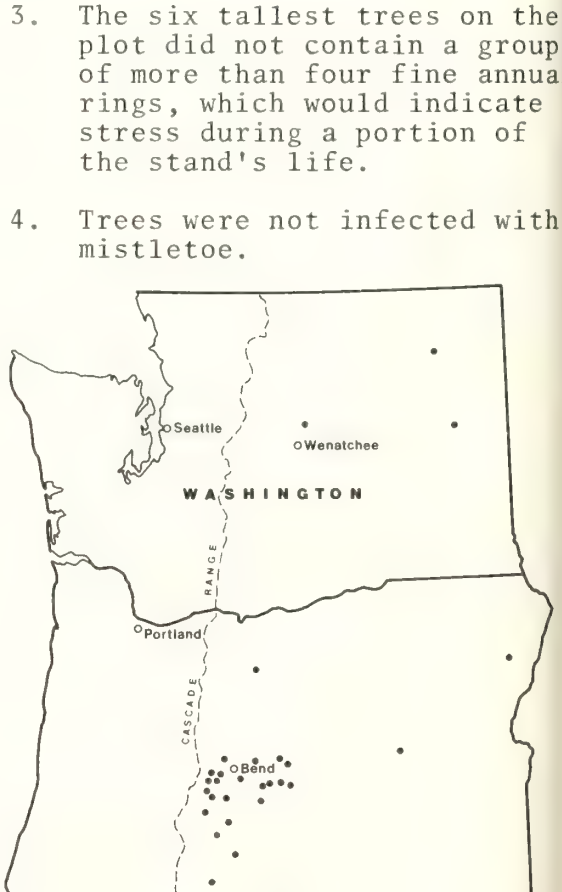


*Figure 1.--Distribution of ponderosa pine stem analysis study plots in Oregon and Washington.*

5. The six tallest trees on the plot did not exhibit crook in the bole which would indicate terminal damage or reduced internodal length from recurring insect attack.

6. The stand or plot did not contain large, old dead, or old living brush that suggested heavy competition from understory vegetation for the trees during the early part of stand development. The usual scattered understory of living brush and/or grass was permitted.

Using a clinometer and tape, I selected the six tallest trees per plot. An increment core was extracted at breast height from each of the six tallest trees and also from some lower crown-class trees to be sure the stand was even aged within 10 years. The six tallest trees per plot were felled, and a section was removed at ground line, at breast height, and at 10-foot intervals above ground until half the total height was reached. The remainder of the tree was sectioned at 5-foot intervals. Tree sections were frozen to prevent molding. Rings were counted on all sections and recorded for the appropriate height.

The data base consists of 3,500 sections from 177 trees at 30 plot locations in Oregon and Washington (fig. 1). Site indices ranged from a high of 145 to a low of 72 at breast-high age of 100 years:

| Number of plots | Site index |
|---|---|
| 6 | 72-89 |
| 12 | 90-109 |
| 9 | 110-129 |
| 3 | 130-145 |

The number of trees on sample stands ranged from a low of 52 per acre to a maximum of 152 on some of the better sites.

## *Results*

The methodology used in developing these curves includes the recent improvements in curve construction suggested by Curtis et al. (1974) and Dahms (1975). This methodology is described in the appendix for the reader who may wish to construct his own curves. Poor estimates of site, however, often result from a lack of adherence to the principles on which the index system was founded. Some understanding of how curves were constructed leads to an appreciation of how they should be used. Therefore, the appendix section on curve construction is recommended reading for even the occasional user of a curve or equation.

Height-over-age relationships for all plots were consistent and reasonably smooth between the ages of 20 and 130 years. Not many plots were found that qualified under the constraints of plot selection beyond 130 years. Under age 20, some curves were erratic; but smoothness improved markedly after age 20 and was consistent thereafter.

## ESTIMATING THE AVERAGE COURSE OF HEIGHT GROWTH FOR STANDS OF A GIVEN SITE QUALITY

Height growth curves define the average pattern of height development on stands of a given site quality. They are appropriately used for constructing yield tables but do not provide optimum estimates of site index from measured height and age in an existing stand (Curtis et al. 1974).

The following are alternatives for estimating the anticipated height of the tallest trees of a stand on land of known site index:

1. Use figure 2 for rough field estimates.

2. For a more precise estimate, table 1 can be used to solve the equation,

Total height - 4.5 feet =
a + b (site index - 4.5 feet).

3. The equation shown in the appendix will be useful for those wishing to program the estimating procedure in a computer.

## ESTIMATING SITE INDEX

Site index curves relate to the productivity potential of land. They give the estimated height of the tallest tree at 100 years in relation to its height and breast-high age. Many of the same plot qualifications used in the study are applicable in selecting plots for estimating site index. The following steps and precautions are recommended for estimating the site index of a managed stand.

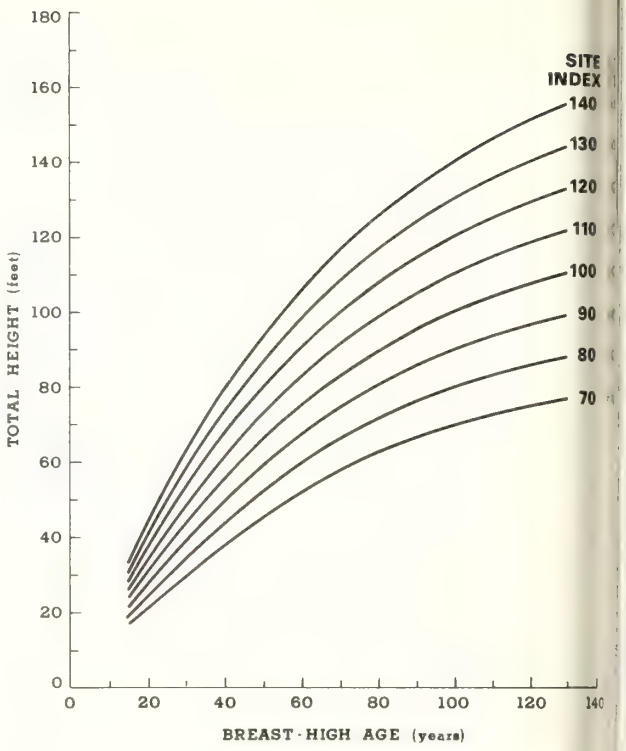


*Figure 2.--Height growth curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. Heights represent the tallest trees in the stand.*

Table 1--Values of a and b by years for the family of regressions[1/] for estimating height of the tallest trees in a newly established stand of ponderosa pine where site index and age are known

| Breast-high age | Years between decades | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | | |
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Years | | | | | | | | | | | | | | | | | | | | | | |
| 20 | -4.834 | [illegible] | -5.132 | 0.342 | -5.381 | 0.359 | -5.587 | 0.375 | -5.755 | 0.390 | -5.887 | 0.406 | -5.988 | 0.420 | -6.061 | 0.434 | -6.108 | 0.448 | -6.132 | 0.4 |
| 30 | -6.136 | .475 | -6.121 | .488 | -6.089 | .500 | -6.043 | .512 | -5.982 | .524 | -5.910 | .536 | -5.828 | .547 | -5.735 | .559 | -5.635 | .569 | -5.527 | .5 |
| 40 | -5.412 | .591 | -5.292 | .601 | -5.167 | .611 | -5.037 | .621 | -4.905 | .631 | -4.769 | .640 | -4.631 | .649 | -4.491 | .659 | -4.350 | .668 | -4.209 | .6 |
| 50 | -4.066 | .685 | -3.924 | .694 | -3.781 | .702 | -3.639 | .711 | -3.499 | .719 | -3.359 | .727 | -3.220 | .735 | -3.083 | .743 | -2.948 | .750 | -2.815 | .7 |
| 60 | -2.684 | .766 | -2.555 | .773 | -2.429 | .780 | -2.305 | .787 | -2.184 | .794 | -2.066 | .801 | -1.951 | .808 | -1.838 | .815 | -1.729 | .822 | -1.623 | .8 |
| 70 | -1.520 | .835 | -1.420 | .841 | -1.324 | .848 | -1.230 | .854 | -1.141 | .860 | -1.054 | .867 | -.971 | .873 | -.892 | .879 | -.816 | .885 | -.743 | .8 |
| 80 | -.674 | .896 | -.608 | .902 | -.546 | .908 | -.487 | .913 | -.431 | .919 | -.379 | .924 | -.331 | .930 | -.285 | .935 | -.244 | .940 | -.205 | .9 |
| 90 | -.170 | .951 | -.138 | .956 | -.109 | .961 | -.084 | .966 | -.062 | .971 | -.043 | .976 | -.027 | .981 | -.014 | .986 | -.005 | .991 | .002 | .9 |
| 100 | .005 | 1.000 | .006 | 1.005 | .004 | 1.009 | -.002 | 1.014 | -.010 | 1.018 | -.021 | 1.023 | -.034 | 1.027 | -.051 | 1.032 | -.070 | 1.036 | -.092 | 1.0 |
| 110 | -.116 | 1.045 | -.143 | 1.049 | -.173 | 1.053 | -.205 | 1.057 | -.239 | 1.061 | -.276 | 1.065 | -.316 | 1.069 | -.357 | 1.073 | -.401 | 1.077 | -.447 | 1.0 |
| 120 | -.496 | 1.085 | -.547 | 1.089 | -.599 | 1.093 | -.654 | 1.097 | -.711 | 1.100 | -.770 | 1.104 | -.831 | 1.108 | -.894 | 1.112 | -.958 | 1.115 | -1.025 | 1.1 |
| 130 | -1.093 | 1.122 | | | | | | | | | | | | | | | | | | | | |

[1/] Height at a future date of the tallest portion of a young stand may be estimated on land of known site index by selecting a and b values for the appropriate breast-high age from the table. Substitute a and b values in the equation (HT - 4.5 feet) = a + b(SI - 4.5) for the particular breast-high age wanted. For example, for the height of the tallest trees in the stand at breast-high age 80 on land with a known site index of 100, solve the equation, HT - 4.5 = -.674 + 0.896(100 - 4.5), for a total height of 89.4 feet.

1. Select a suitable plot with the following characteristics:

   (a) even-aged within 10 years,

   (b) no disease symptoms that would affect height,

   (c) no fine ring groups to indicate growth suppression,

   (d) internodal lengths consistent on taller trees,

   (e) no remnant understory vegetation that would indicate competition during early part of the stand's life.

2. Establish boundaries of a circular 1/5-acre plot.

3. Measure height of the tallest tree on the plot.

4. Extract increment cores from the three tallest trees on the plot to obtain an average breast-high stand age.

5. From breast-high age and total height, estimate the site index by one or more of the following alternatives.

   (a) Use figure 3 for rough field estimates.

   (b) For a more precise estimate, table 2 can be used to solve the equation,

Site index - 4.5 feet =
a + b (height - 4.5 feet).

   (c) The equation shown in the appendix will be useful for those wishing to program the estimating procedure in a computer.

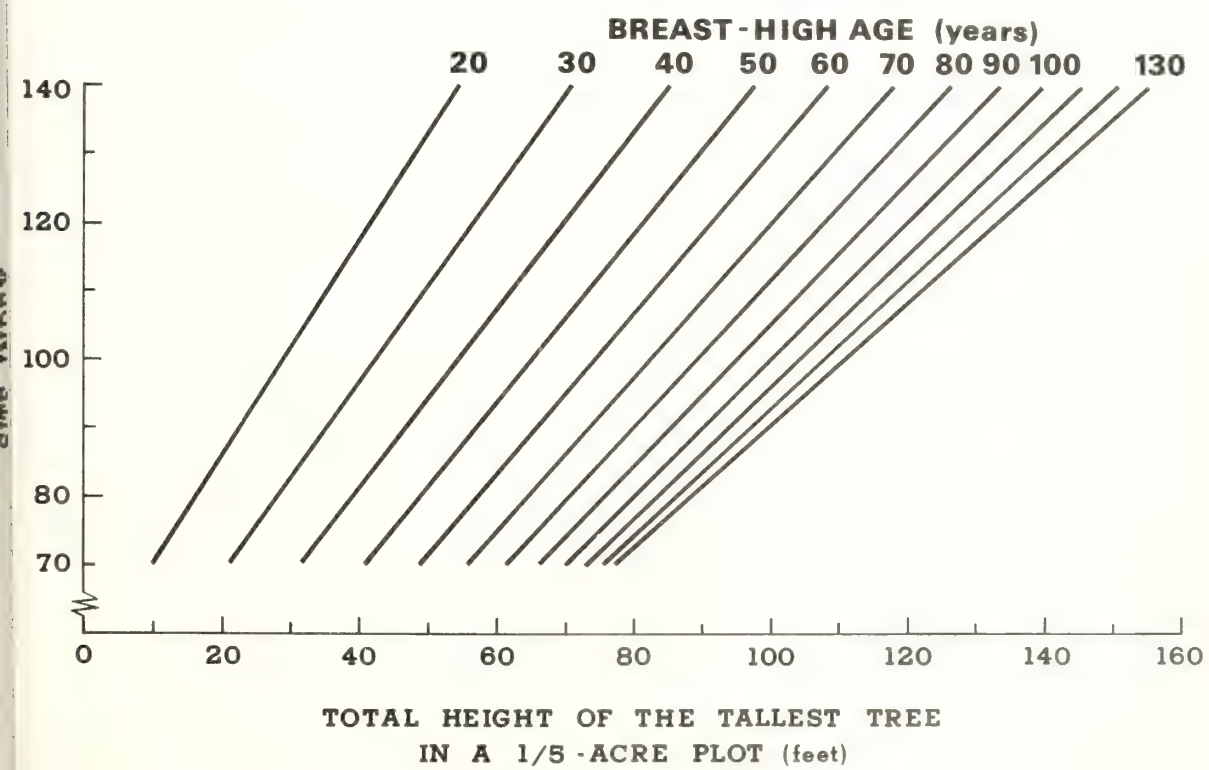


*Figure 3.--Site index curves for even-aged, managed stands of ponderosa pine in the Pacific Northwest.*

Table ---. [illegible] for the family of regressions[1/] for estimating site index for ponderosa pine in the Pacific Northwest

| Breast-high age | Years between decades | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | |
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Years | | | | | | | | | | | | | | | | | | | | |
| [illegible] | [illegible] | 1.564 | [illegible] | 1.541 | 53.835 | 1.520 | 52.318 | 1.501 | 50.828 | 1.483 | 49.365 | 1.466 | 47.929 | 1.450 | 46.519 | 1.435 | 45.135 | 1.421 | 43.778 | 1.4 |
| 40 | 42.447 | 1.395 | 41.143 | 1.383 | 39.864 | 1.372 | 38.611 | 1.361 | 37.384 | 1.351 | 36.182 | 1.341 | 35.005 | 1.331 | 33.854 | 1.322 | 32.727 | 1.313 | 31.624 | 1.3 |
| [illegible] | 30.546 | 1.297 | [illegible] | 1.289 | 28.461 | 1.281 | 27.454 | 1.273 | 26.470 | 1.266 | 25.510 | 1.259 | 24.571 | 1.252 | 23.655 | 1.245 | 22.762 | 1.239 | 21.890 | 1.2 |
| 50 | 21.039 | 1.226 | [illegible] | 1.220 | 19.402 | 1.214 | 18.615 | 1.208 | 17.847 | 1.202 | 17.100 | 1.196 | 16.373 | 1.191 | 15.665 | 1.185 | 14.977 | 1.180 | 14.307 | 1.1 |
| 60 | 13.656 | 1.170 | [illegible] | 1.164 | 12.410 | 1.159 | 11.813 | 1.154 | 11.234 | 1.149 | 10.673 | 1.145 | 10.128 | 1.140 | 9.600 | 1.135 | 9.089 | 1.130 | 8.594 | 1.1 |
| 70 | 8.114 | 1.121 | [illegible] | 1.117 | 7.203 | 1.112 | 6.770 | 1.108 | 6.353 | 1.103 | 5.949 | 1.099 | 5.561 | 1.095 | 5.186 | 1.090 | 4.826 | 1.086 | 4.479 | 1.0 |
| 80 | 4.146 | 1.078 | [illegible] | 1.074 | [illegible] | 1.069 | 3.226 | 1.065 | 2.945 | 1.061 | 2.676 | 1.057 | 2.419 | 1.053 | 2.175 | 1.049 | 1.942 | 1.045 | 1.720 | 1.0 |
| 90 | 1.510 | 1.038 | [illegible] | 1.034 | 1.124 | [illegible] | [illegible] | 1.026 | .781 | 1.022 | .625 | 1.019 | .479 | 1.015 | .343 | 1.011 | .217 | 1.007 | .101 | 1.0 |
| 100 | -.005 | 1.000 | .103 | .996 | -.191 | .993 | -.270 | .989 | -.340 | .985 | -.402 | .982 | -.455 | .978 | -.500 | .975 | -.536 | .971 | -.565 | [illegible] |
| 110 | -.585 | [illegible] | [illegible] | .960 | -.603 | .957 | -.601 | .953 | -.591 | .950 | -.574 | .947 | -.550 | .943 | -.519 | .940 | -.481 | .936 | -.437 | |
| 120 | [illegible] | .929 | [illegible] | .926 | -.264 | .922 | -.194 | .919 | -.118 | .916 | -.036 | .912 | .052 | .909 | .146 | .906 | .245 | .902 | .350 | [illegible] |
| 130 | .460 | .896 | | | | | | | | | | | | | | | | | | |

[1/] To estimate site index, measure total height of the tallest tree per 1/5-acre plot. Determine average breast-high stand age from at least three of the tallest trees per plot. Select appropriate a and b value above. Substitute values in the equation (SI - 4.5 feet) = a + b(HT - 4.5). For example, for a tree 53 years old at breast height and 60 feet in total height, solve the equation, SI - 4.5 = 18.615 + 1.208(60 - 4.5), for a site index of 90.

## Application

In this study, site index is a number representing the height of the tallest tree on a 1/5-acre plot at a breast-high age of 100 years. Since site has been found to be closely correlated with volume, site (as discussed here) will later be used in a yield study to categorize volume productivity potentials of managed stands of ponderosa pine. Past experience has shown that height objectively reflects site where stands are not overstocked or understocked. Managed stands, in contrast to natural stands, probably will not be overstocked to the point of substantially affecting height growth. Therefore, use of these curves should be restricted to managed stands where height growth competition between trees has been held to a minimum.

Typical examples of when the curves should not be used are:

1. precommercially thinned stands showing a tight core of rings;

2. commercially thinned stands with numerous stumps indicating a high initial density; and

3. plantations with large numbers of trees and thinned long after competition between trees occurred.

These curves may have limited field application for some time because there is only a limited amount of land under intensive management that fits the constraints of the curves. Greatest use is in forecasting future stand performance in a stand growth simulator. One should note, however, that these curves represent the tallest trees. Stand projections should assign appropriate lesser heights to the other trees.

Reliability of the curves can be partially judged by the $r^2$ values and the standard errors of estimate shown in the appendix. Also, one may judge equation fit from figures 8 and 9 in the appendix. A portion of the data from 20 plots was destroyed in the Bend Silviculture Laboratory fire, of January 15, 1974. If this data had been available, an annual comparison of actual and predicted values could have been made, similar to that made by Johnson and Worthington (1963).

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# *Appendix*

## CONSTRUCTION OF SITE INDEX AND HEIGHT GROWTH CURVES [2/]

The following steps were used in constructing the site index curves:

1. Average breast-high stand age for each plot was calculated from the six felled trees. Total height was plotted over breast-high age. The six trees were plotted on the same graph. Height of the tree that was tallest at a specific age to 130 years was read from the graph. Shifts[3/] in relative height similar to those reported by Dahms (1963) were found in 90 percent of the plots. Site index was read from the graph of the tallest tree at breast high age of 100 years.

2. The basic equation form is

$$SI - 4.5 \text{ feet} = a + b\,(HT - 4.5 \text{ feet});$$

where, HT = total height and
SI = site index.

Linear regressions of this form were calculated for each decade starting with 10 years and ending with 130 years. Following is a list of these regressions:

| Breast-high age (years) | Site index (SI) | | a | | b | Total height (HT) | $r^2$ | Standard error of estimate | Number of observations |
|---|---|---|---|---|---|---|---|---|---|
| 10 | -4.5 | = | 69.8003 | + | 1.9825 | -4.5 | 0.23 | 15.8 | 30 |
| 20 | -4.5 | = | 52.8113 | + | 1.6807 | -4.5 | .50 | 12.7 | 30 |
| 30 | -4.5 | = | 43.6947 | + | 1.3845 | -4.5 | .64 | 10.8 | 30 |
| 40 | -4.5 | = | 35.2987 | + | 1.2269 | -4.5 | .74 | 9.2 | 30 |
| 50 | -4.5 | = | 23.5422 | + | 1.1966 | -4.5 | .83 | 7.3 | 30 |
| 60 | -4.5 | = | 16.1510 | + | 1.1322 | -4.5 | .90 | 5.7 | 30 |
| 70 | -4.5 | = | 10.0630 | + | 1.0986 | -4.5 | .94 | 4.3 | 30 |
| 80 | -4.5 | = | 5.1357 | + | 1.0717 | -4.5 | .97 | 3.1 | 30 |
| 90 | -4.5 | = | 1.3892 | + | 1.0456 | -4.5 | .99 | 2.0 | 30 |
| 100 | -4.5 | = | 0.0000 | + | 1.0000 | -4.5 | 1.00 | 0.0 | 30 |
| 110 | -4.5 | = | 3.4683 | + | 0.9164 | -4.5 | .99 | 1.2 | 28 |
| 120 | -4.5 | = | 5.5218 | + | 0.8598 | -4.5 | .99 | 1.8 | 25 |
| 130 | -4.5 | = | 1.0876 | + | 0.8848 | -4.5 | .98 | 2.0 | 11 |

---

[2/] The methodology developed by Dahms (1975) was used to derive the site index and height growth equations. The methodology is repeated here so the reader may judge the quality of various relationships. In addition, equation derivation is explained for those who wish to use this method to construct their own curves.

[3/] For example, the tallest tree in the stand at age 50 may not be the tallest at age 80.

3. The above decadal estimates of b were smoothed over age (fig. 4) by the equation,

$$\hat{b} = 1.198632 - 0.0028307A + 8.4441\ (1/A);$$

where, A = breast high age

The resulting $\hat{b}$ values are those appearing in table 2.

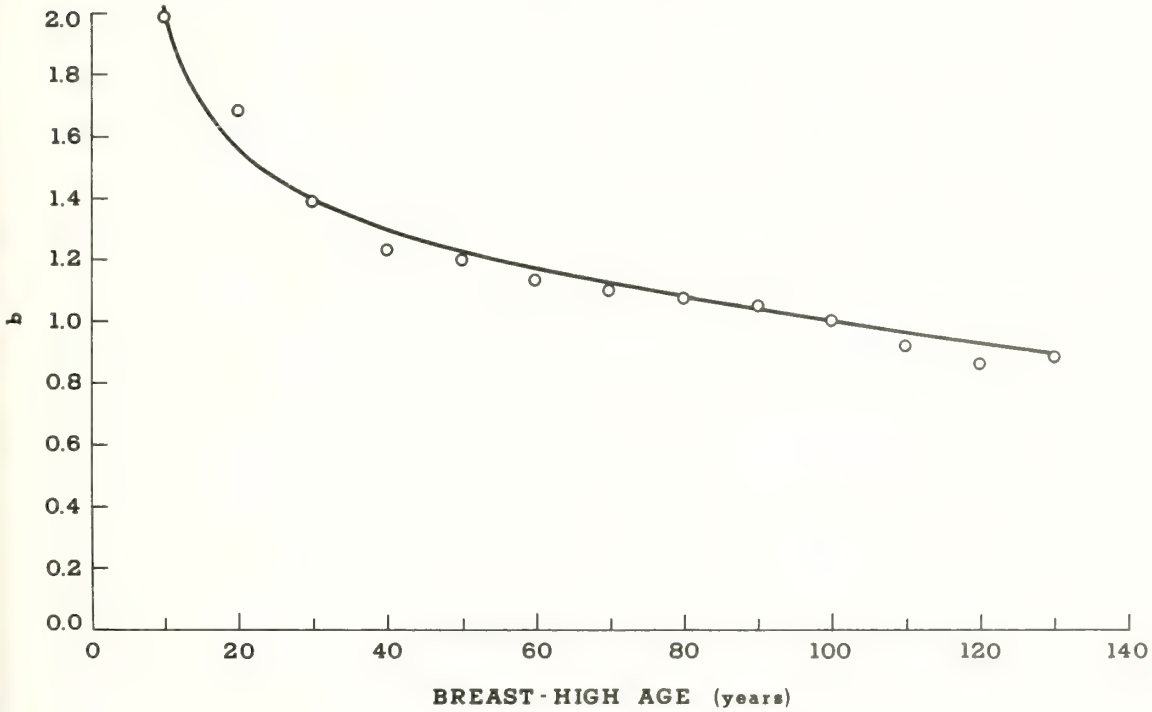


*Figure 4.--b values in the equation SI - 4.5 feet = a + b (HT - 4.5 feet) as a function of age. X = actual b values. Solid line is curve expressed by the equation, b = 1.198632 - 0.0028307 age + 8.44441 (1/A).*

4. The following equation, expressing decadal mean heights as a function of age, was conditioned to pass through mean site index ($\overline{SI}$) 100.43 (+4.5) at 100 years (fig. 5).

$$\hat{HT} - 4.5 = 128.895 \left(1 - e^{-0.016959A}\right)^{1.23114}.$$

At ages beyond 100 years the sample became progressively smaller and mean site index was slightly different. Heights were adjusted to the mean overall site index before fitting the average height curve.

5. Since average height, $\hat{HT}$, from years 10 through 130 was known as well as slope $\hat{b}$ of regressions for each year, the corre-

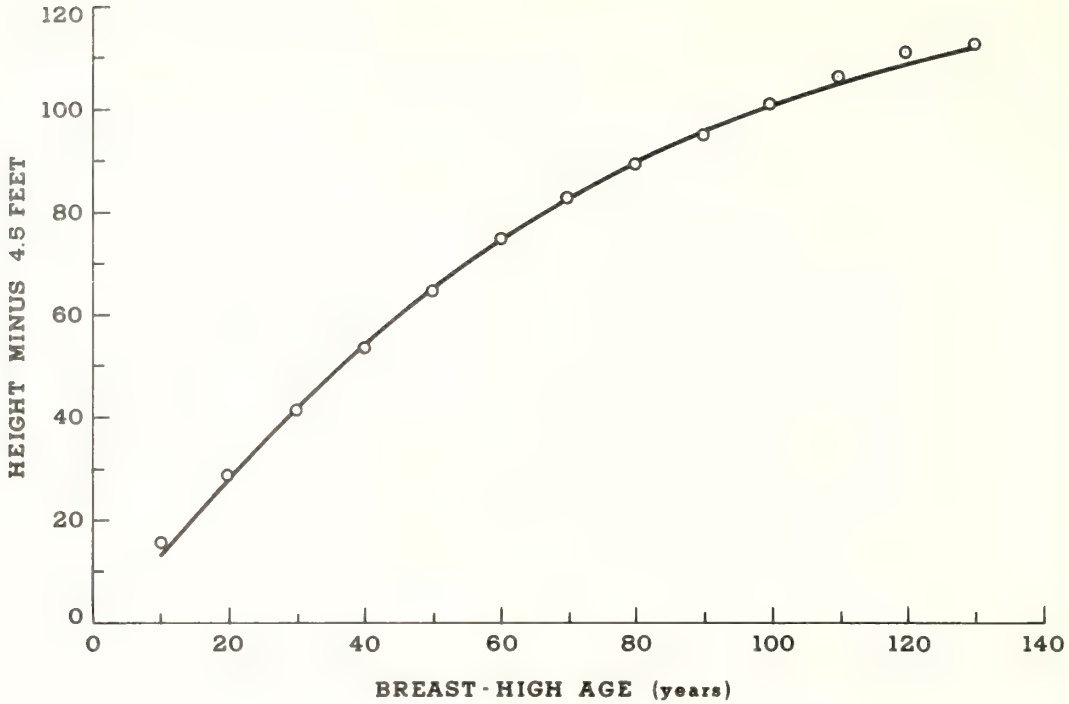


*Figure 5.--Average height of sectioned trees as a function of breast-high age. X = average height. Solid line is curve expressed by equation*

$$\hat{HT} - 4.5 \text{ feet} = 128.895 \left(1 - e^{-0.016959\ age}\right)^{1.23114} .$$

sponding intercept a could be calculated. By substituting the following in the basic equation of step 2:

$$\overline{SI} - 4.5 = a + \hat{b}\ (\hat{HT} - 4.5),$$

therefore, $\hat{a} = \overline{SI} - 4.5 - \hat{b}\ (\hat{HT} - 4.5)$.

The resulting $\hat{a}$ values are those shown in table 2.

6. Substituting $\hat{a}$, $\hat{b}$, and $\hat{HT}$ in the basic equation of step 2 gives the final equation used to estimate site index as a function of age and height (fig. 3).

$$SI - 4.5 = 100.43 - [1.198632 - 0.00283073\ age + 8.44441\ /age] \cdot \left[128.8952205 \left(1 - e^{-0.016959\ age}\right)^{1.23114}\right] + \left[(1.198632 - 0.00283073\ age + 8.44441\ /age) \cdot (HT - 4.5)\right] .$$

Construction of the height growth curves was similar. Since we are now interested in attainable height when age and site index are known, the basic equation is reversed from the previous example where site index was estimated and we now have

$$HT - 4.5 = a + b\,(SI - 4.5).$$

1. The data accumulated in step 1 of site index curve construction is used for constructing height growth curves.

2. Linear regressions of this form were calculated for each decade starting with 10 and ending with 130 years. Following is a list of these regressions:

| Breast-high age (years) | Total height (HT) | | a | | b | Site index (SI) | $r^2$ | Standard error of estimate | Number of observations |
|---|---|---|---|---|---|---|---|---|---|
| 10 | -4.5 | = | 3.8003 | + | 0.1162 | -4.5 | .23 | 3.8 | 30 |
| 20 | -4.5 | = | -1.5177 | + | 0.2974 | -4.5 | .50 | 5.3 | 30 |
| 30 | -4.5 | = | -5.5801 | + | 0.4637 | -4.5 | .64 | 6.2 | 30 |
| 40 | -4.5 | = | -7.2401 | + | 0.6008 | -4.5 | .74 | 6.5 | 30 |
| 50 | -4.5 | = | -5.7960 | + | 0.6976 | -4.5 | .83 | 5.6 | 30 |
| 60 | -4.5 | = | -5.5043 | + | 0.7960 | -4.5 | .90 | 4.7 | 30 |
| 70 | -4.5 | = | -3.9442 | + | 0.8583 | -4.5 | .94 | 3.8 | 30 |
| 80 | -4.5 | = | -1.9355 | + | 0.9046 | -4.5 | .97 | 2.9 | 30 |
| 90 | -4.5 | = | -0.1844 | + | 0.9450 | -4.5 | .99 | 1.9 | 30 |
| 100 | -4.5 | = | 0.0000 | + | 1.0000 | -4.5 | 1.00 | 0.0 | 30 |
| 110 | -4.5 | = | -3.2803 | + | 1.0861 | -4.5 | .99 | 1.3 | 28 |
| 120 | -4.5 | = | -5.1488 | + | 1.1500 | -4.5 | .99 | 2.1 | 25 |
| 130 | -4.5 | = | 0.4011 | + | 1.1111 | -4.5 | .98 | 2.2 | 11 |

3. The above decadal estimates of b were smoothed over age (fig. 6) by the equation,

$$\hat{b} = -0.7864 + 2.49717 \left(1 - e^{-0.0045042A}\right)^{0.33022}.$$

The resulting $\hat{b}$ values are those appearing in table 1.

4. The same expression for decadal mean height used in determining site index was used again.

$$\hat{HT} - 4.5 = 128.895 \left(1 - e^{-0.016959A}\right)^{1.23114}.$$

5. Substituting mean site index $\overline{SI} = 100.43$ in the basic equation:

$$\hat{HT} - 4.5 = a + \hat{b}\,(\overline{SI} - 4.5);$$

therefore, $\hat{a} = \hat{HT} - 4.5 - \hat{b}\,(\overline{SI} - 4.5)$.

The resulting a values are those shown in table 1.

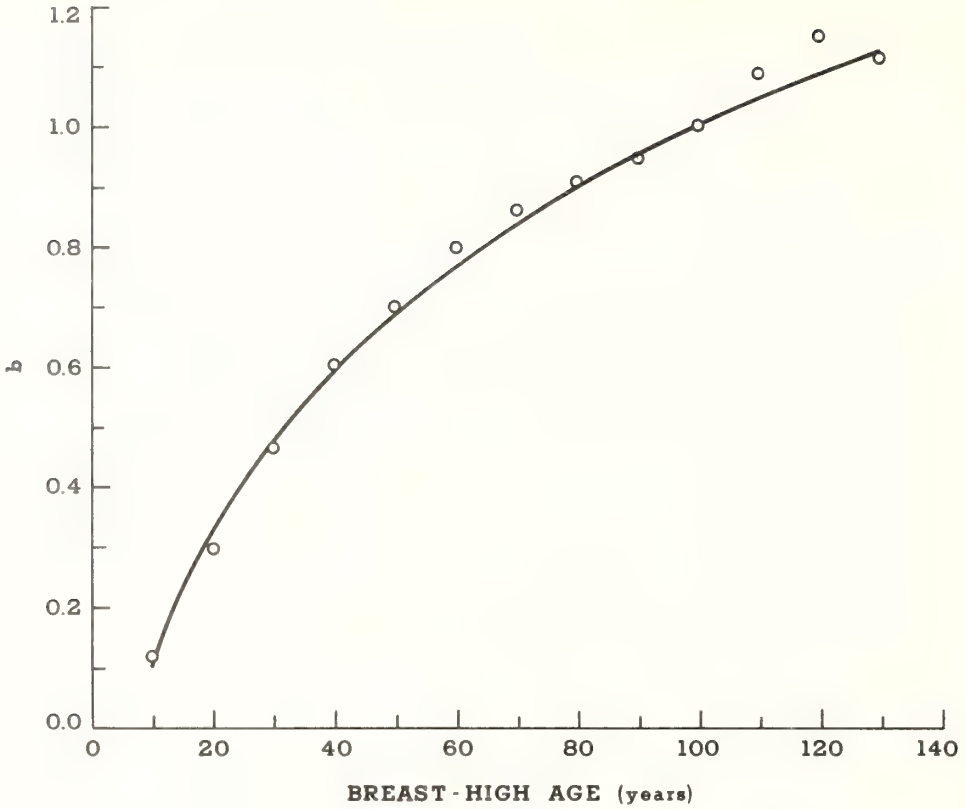


*Figure 6.--b values in the equation HT - 4.5 feet = a + b (SI - 4.5 feet) as a function of age. X = actual b value. Solid line is curve expressed by the equation*

$$b = -0.7864 + 2.49717 \left(1 - e^{-0.0045042\ age}\right)^{0.33022}$$

6. Substituting $\hat{a}$, $\hat{b}$, and $\hat{HT}$ in the basic equation HT - 4.5 = a + b (SI - 4.5) gives the final equation used to estimate height as a function of age and site index as shown in figure 2.

$$HT - 4.5 = \left[128.8952205 \left(1 - e^{-0.016959\ age}\right)^{1.23114}\right] - \left[\left(-0.7864 + 2.49717 \left(1 - e^{-0.0045042\ age}\right)^{0.33022}\right) \cdot \left(100.43\right)\right] + \left[\left(-0.7864 + 2.49717 \left(1 - e^{-0.0045042\ age}\right)^{0.33022}\right) \cdot \left(SI - 4.5\right)\right].$$

A graphic comparison between site index and the height growth curves is shown in figure 7.

The final estimating equations for both site and height fit the basic data regression points well. Some deviations occurred at sites and ages above 100 (figs. 8 and 9).

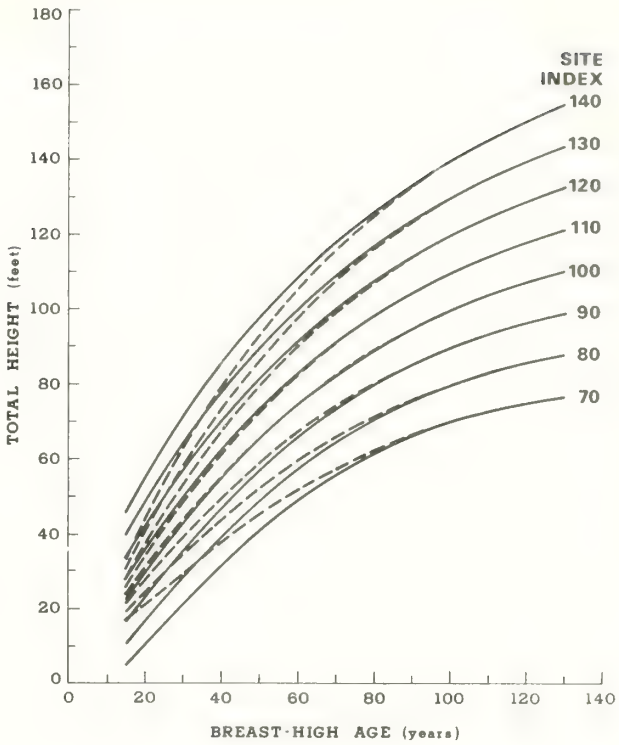


*Figure 7.--Site index (solid lines) and height growth curves (dashed lines) for even-aged managed stands of ponderosa pine in the Pacific Northwest.*

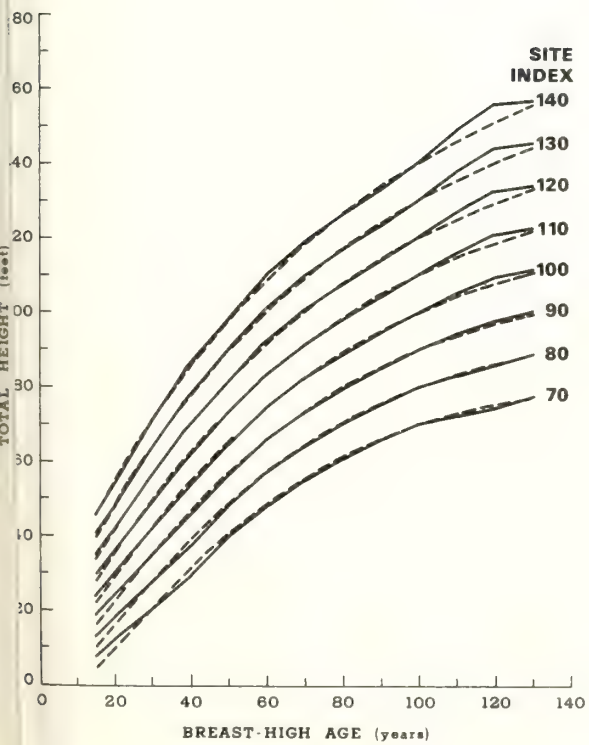


*Figure 8.--Site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. Solid lines connect decadal points derived from the unsmoothed basic data regressions of $SI - 4.5 = a + b(HT - 4.5)$. Dashed lines represent smooth curves from the estimating equations.*

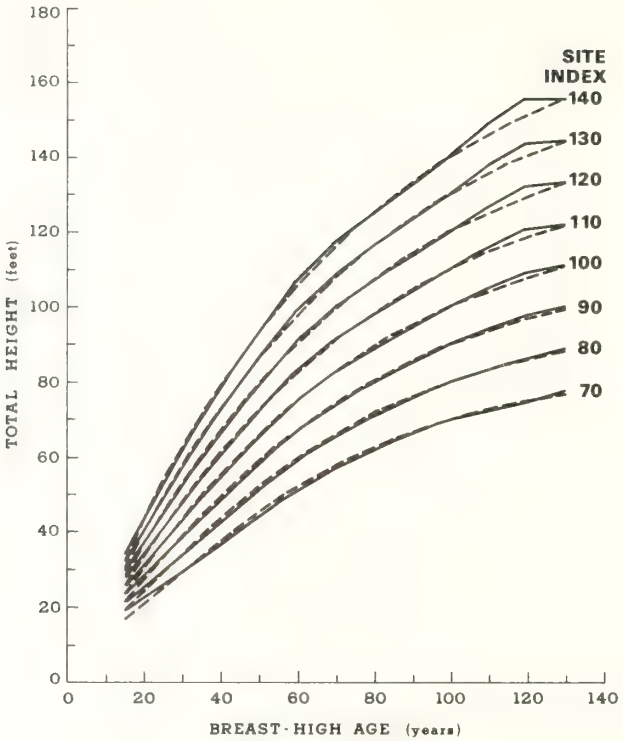


*Figure 9.--Height growth curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. Solid lines connect decadal points derived from the unsmoothed basic data regressions of HT - 4.5 = a + b(SI - 4.5). Dashed lines represent smooth curves from the estimating equations.*



GPO 985-641

Barrett, James W.
1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-232, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This paper presents height growth and site index curves and equations for even-aged, managed stands of ponderosa pine east of the Cascade Range in Oregon and Washington where height growth has not been suppressed by high density or related factors.

KEYWORDS: Increment (height), site index -)stand height/ age, measurement systems, stem analysis, ponderosa pine, *Pinus ponderosa*, Oregon (eastern), Washington (eastern).

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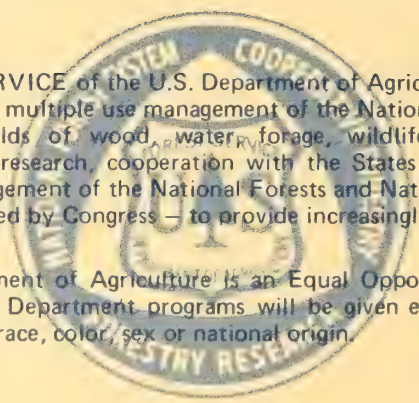

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USDA FOREST SERVICE RESEARCH PAPER PNW-233
1978

# ree Mortality and Top-kill Related To Defoliation by the Douglas-Fir Tussock Moth in the Blue Mountains Outbreak

Boyd E. Wickman

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

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# *Tree Mortality and Top-kill Related to Defoliation by the Douglas-fir Tussock Moth in the Blue Mountains Outbreak*

*Reference Abstract*

Wickman, Boyd E.
1978. Tree mortality and top-kill related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA For. Serv. Res. Pap. PNW-233, 47 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Tree mortality and top-kill resulting from defoliation by the Douglas-fir tussock moth in 1972 and 1973 in the Blue Mountains has been measured in the field annually since 1973 on a series of permanent plots. This paper summarizes tree mortality and top-kill through 1976. The study was designed to use defoliation intensity in 1972 and 1973 as a predictor of tree mortality and top-kill during and after the outbreak. Results of the study show that the pattern of tree mortality conforms to that of previous outbreaks studied in California white fir. Mortality increases with defoliation intensity, and most mortality occurs in trees defoliated 90 percent or more. Mortality summarized by four defoliation classes showed that areas classed as having heavy defoliation suffered 72 percent (number of trees) of the stand killed: moderate, 5.2 percent killed; light, 6.3 percent killed; and very light, 11.1 percent killed. The data indicate that Douglas-fir suffers proportionally more tree mortality than grand fir. Douglas-fir comprises about 20 percent of the stand on the plots, but the total percent stand mortality almost equals grand fir mortality.

The pattern of top-kill is similar to that of tree mortality; trees suffering most defoliation have the highest incidence and severity of top-kill. A breakdown by defoliation class in surviving trees shows that top-kill incidence was as follows: heavy defoliation class, 35.4 percent top-kill; moderate, 11.9 percent; light, 4.6 percent; and very light 5.9 percent. And Douglas-fir suffered twice as much top-kill as grand fir.

KEYWORDS: Insect damage (-forest, defoliation damage, Douglas-fir tussock moth, *Orgyia pseudotsugata*, Douglas-fir, *Pseudotsuga menziesii*, grand fir, *Abies grandis*, Oregon (Blue Mountains), Washington (Blue Mountains).

*RESEARCH SUMMARY*

*Research Paper PNW-233*
*1978*

The data gathered in this study can be used for determining net impact on stand growth, but it is primarily meant to show the relation of insect populations (Mason 1976), through the pathway of tree defoliation, to tree mortality and top-kill. The effects of individual-tree damage on stand productivity through a rotation period is a study in itself and will be reported elsewhere.

Tree mortality was related to degree of defoliation, with 90 percent or more of the mortality occurring in trees 90-percent or more defoliated. Mortality caused by secondary attacks of bark beetles was concentrated in grand fir suffering 75-percent or greater defoliation; but, in Douglas-fir, mortality caused by Douglas-fir beetle was more evenly distributed in all defoliation classes. Mortality caused by bark beetles was not as high as in some past outbreaks in California (Wickman 1963). The intensive logging activity throughout the outbreak area since 1973 and 2 years of subnormal precipitation are thought to have contributed to increases in Douglas-fir beetle populations. Tree mortality was fairly evenly distributed through all d.b.h. classes.

Tree mortality as related to the defoliation classes mapped in 1972 showed that the heaviest mortality occurred in the areas classed as having heavy defoliation (38.6 percent). Mortality in moderately and lightly defoliated areas was lower (10.6 and 5.3 percent, respectively). Some areas with very light defoliation suffered mortality in 1973 similar to that of areas in the heavy defoliation class in 1972, but the average for the entire class (12.6 percent) was still about one-third as high as in heavy defoliation class areas. Differences were found in the calculated mortality levels for each class depending on how plots were stratified. The most accurate method was to stratify individual plots within a cluster into their respective defoliation classes: all moderate class plots in the moderate class strata, all light class in the light strata, and so on. A mapped defoliation class was often composed of a mixture of several classes. When tree mortality was related to defoliation classes composed of stratified plots, the following levels of mortality were determined: heavy defoliation class areas, 72 percent; moderate, 5.2 percent; light, 6.3 percent; and very light, 11.1 percent. The greatest discrepancies between the two summaries are in the heavy and moderate classes. Tree mortality in the heavy areas (72 percent) was similar to patches of mortality found in an earlier California outbreak (Wickman et al. 1973).

Mortality was related to year and years of defoliation (1972 and 1973). Heavy defoliation class areas suffered their most severe defoliation in 1972, and the highest mortality rates for any class during the outbreak were found in these areas. Little additional defoliation occurred on heavy class areas in 1973, so the inference is that 1972 defoliation caused some of the most severe tree mortality of the outbreak. In 1973, more acres were defoliated, and defoliation was especially intense in those areas having a high proportion of Douglas-fir in the stand. Some of these areas had patches of tree mortality similar to 1972 heavy defoliation class areas.

One significant finding of the study, as it relates to forest management practices in the Blue Mountains, was the differential mortality between grand fir and Douglas-fir. In 1972, mortality of the two species was about equal; but after 1973 defoliation Douglas-fir suffered much higher rates. This is particularly significant because Douglas-fir averaged only 19.7 percent of the stand in our study areas, but

suffered almost the same total amount of mortality as grand fir by 1976. We found that, individually, Douglas-fir trees are probably not more susceptible to mortality from a given level of defoliation. Some attribute of environmental conditions reflected by stand composition in terms of percent Douglas-fir probably contributes to this higher loss and possibly even the higher mortality of grand fir when it is associated with Douglas-fir. We explored this relation further and found that stands containing 50 percent or more Douglas-fir suffered the highest mortality rates in 1973. Regression analysis indicated that a positive and significant correlation did exist between total mortality of both host species and the percent of Douglas-fir in the stand. This relation may not be the same for other geographical areas and should be studied further, but it does have some strong implications for forest managers in the Blue Mountains.

Five top-kill classes were related to individual-tree defoliation categories. The most severe top-kill occurred in the trees suffering highest amounts of defoliation, and leader damage was the most common class of top-kill followed by the class that had 1 to 10 percent of the crown top-killed. Severe top-kill (greater than 25 percent of the crown) amounted to 2 percent of the total for both species, and most of this damage occurred in trees defoliated 75 percent or more.

Top-kill class was also related to d.b.h. class. In grand fir, 17 percent of the trees with larger than 12-inch d.b.h. suffered top-kill exclusive of leader-only damage. In Douglas-fir, 13 percent of trees with larger than 12-inch d.b.h. suffered top-kill exclusive of leader-only damage. Long-term effects of top-kill are probably more serious in trees with smaller than 12-inch d.b.h. In grand fir, 4.3 percent of the trees in the 1- to 6-inch d.b.h. class and 12.9 percent of the trees in the 7- to 11-inch d.b.h. class suffered top-kill exclusive of leader-only damage. In Douglas-fir, the concentration of top-damage in these d.b.h. classes was much higher at 14.6 and 21.1 percent, respectively.

Distribution of top-kill in the four defoliation classes was also summarized. When top-damage was stratified by the mapped defoliation class areas most of the top-kill occurred in Douglas-fir, and the top damage was fairly evenly distributed through all four classes for both species. When stratified by the individual-plot defoliation class areas, top-kill was concentrated in the heavy class for grand fir and the heavy and moderate classes for Douglas-fir.

When all grand fir and Douglas-fir top-kill are compared, the trends for each species are similar; but Douglas-fir suffered more than double the total amount of top-kill, exclusive of leader-only damage.

Top-kill was also related to mortality caused by bark beetles after the outbreak. Small sample size prevented statistical analysis, but trees of both species with more than 50 percent of the crown top-killed apparently have a high probability of being killed by bark beetles the first several years after a Douglas-fir tussock moth outbreak.

The main conclusion from the study is that defoliation intensity can be used as a predictor of tree damage, both for individual trees and defoliation class areas. Heavy defoliation in 1972 caused more severe damage than similar defoliation on some light and very light class areas in 1973, even though 1973 populations were more dense. This anomaly was most likely related to higher larval survival rates in 1972 than 1973 (Mason 1976). Defoliation in 1973 was also more intense on Douglas-fir in the light and very light defoliation class areas; and this relates to very high population levels in these areas in 1973 (Mason 1976), differential larval feeding behavior (Beckwith 1976), and probably physiographic features of the sites.

## Introduction

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a native insect and major defoliator of Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and true fir, *Abies* spp., forests in western North America. Outbreaks of this insect have periodically damaged large amounts of timber; since 1945, forest managers have been concerned enough with the damage potential of the insect to treat most major outbreaks with chemicals.

Most individual tussock moth outbreaks pass through three phases, which usually last about 1 year each. They are: a release phase, with rapid population growth; an outbreak phase, characterized by peak population densities; and a decline phase, ending in complete population collapse (Mason 1974, 1976; Wickman et al. 1973).

Several studies of tree damage have been made after past outbreaks; but all have been in California on one host, white fir, *Abies concolor* (Gord. and Glend.) Lindl., and only during or *after* the decline phase (Wickman 1963, Wert and Wickman 1970). Because most outbreaks are discovered from visible defoliation, the study of damage has usually been a postmortem tabulation after the outbreak collapses. In two California outbreaks, a study of damage was started during the decline phase, so some estimates of individual-tree defoliation were possible (Wickman 1963).

Recently a very large outbreak occurred in the Blue Mountains of northeastern Oregon and southeastern Washington. The infestation was detected and mapped during the outbreak phase and thus afforded a unique opportunity for study of the relation of this insect's population dynamics to tree damage. Life tables for declining populations of the tussock moth in this outbreak were recently published (Mason 1976). Mason determined that defoliation intensity in the first year that the outbreak was detected was a predictor of population trend the next year. An integral part of such prediction, for pest management purposes, is the relation between population level and trends, reflected in defoliation intensity. Levels of defoliation for individual trees can then be used to predict expected tree damage. Southwood (1966) points out the difficulties of determining this relation and recommends that correlation of the two variables should ideally be made in the same location. He does not have a suggestion for doing this under the outbreak conditions we encountered, however. Therefore, the objective of this companion study was to use defoliation intensity in 1972 and 1973 as a predictor of tree damage during and after the outbreak. In this paper, I summarize two important aspects of tree damage: tree mortality and top-kill as they are related to defoliation. The study is unique in that the relations are also mathematically represented elsewhere in model form.[1/] Growth reduction resulting from defoliation will be reported later.

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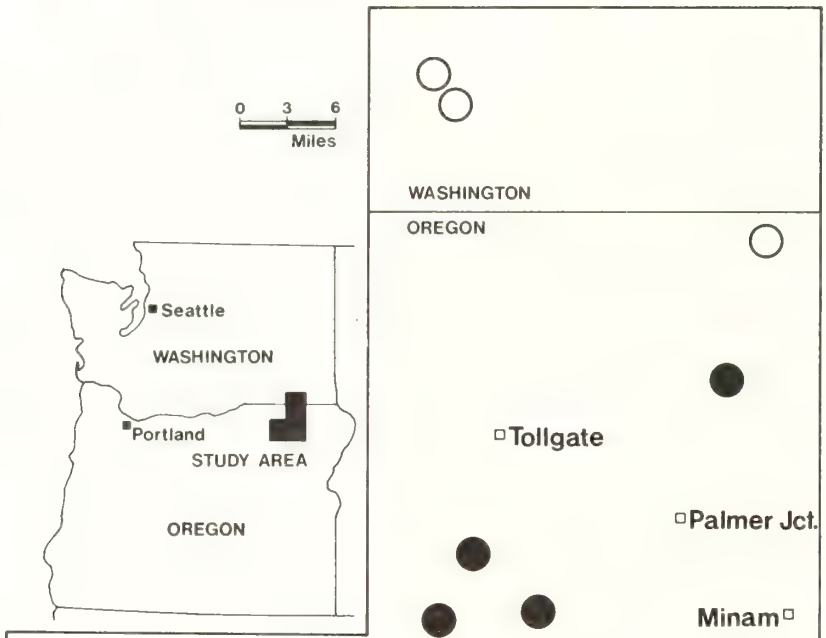
[1/] Overton, W. S., and J. J. Colbert. 1976. Tussock moth population dynamics and tree and stand interaction model. Annual Progress Report, Douglas-fir Tussock Moth Expanded Research and Development Program, Portland, Oregon.

## Methods

### *LOCATION AND DEFOLIATION CLASSES*

As reported by Mason (1976), these studies were conducted in the Blue Mountains of northeastern Oregon (some of my plots are also located in southeastern Washington). Plots were located in the Umatilla National Forest and the Wallowa-Whitman National Forest. The zone of my study covered about a 100-km transect of the tussock moth outbreak mapped by the USDA Forest Service in 1972 (fig. 1). They mapped the outbreak according




● Replicated study areas

○ Additional study areas in heavy defoliation classes

*Figure 1.--Map showing location of tree-damage plot clusters in northeastern Oregon.*

to visible defoliation from aerial and ground surveys in fall 1972 and stratified it into defoliation classes. Mason (1976) defined these classes as: *heavy*, >50 percent of trees completely defoliated; *moderate*, >50 percent of trees one-quarter defoliated; *light*, visible defoliation (from the air) only; and *very light*, no visible defoliation, but new egg masses present.

### *EXPERIMENTAL DESIGN*

The study was designed to use plots established for population studies by Mason as follows (from Mason 1976): "Six replications were established over the zone of study. Four replications contained study plots in each of the four defoliation classes. The remaining two replications contained only three study areas each because areas of heavy defoliation could not be located. Thus, 22 study plots were involved in the investigation. All plots in a replication were located approximately within the same square mile. They were established between 1 219- and 1 524-m elevation either in pure forest stands of grand fir, *Abies grandis* (Dougl.) Lindl., or in stands with a mixture of grand fir and Douglas-fir." I expanded my plot areas to include heavy class areas at the south end of the outbreak and in the Wenaha back country of Oregon and Washington, because areas in this class were being salvaged rapidly by the Forest Service wherever roads existed. I also included one plot area of heavy defoliation class in a pure Douglas-fir stand at 850-m elevation at the south end of the transect. At this point my design differs from Mason's because of the nature of tree damage studies. Clusters of 15 trees were used for the population work; but the damage studies were conducted on clusters of 1/50th-acre, circular plots superimposed around each of Mason's (1976) plots. Each replicate contained a cluster consisting of 5 to 25 ($\bar{X}$ = 10) plots shaped as a square, U, or straight line depending on the available acres of forest type and damage. Plots were 1 chain (20.12 m) apart, center to center. Every plot was staked in the center, and every tree over 1-inch (2.54-cm) d.b.h. was tagged at breast height for future location and identity.

None of the study areas was treated by insecticide although spray tests and control operations were conducted in nearby forests in 1973 and 1974.

### *SAMPLING TECHNIQUES*

The following information was recorded for each tree: species (for both host and nonhost), diameter at breast height (to the nearest .2 inch or .5 cm), crown class (dominant, codominant, intermediate, suppressed), percent defoliation in 1972 and 1973 (see fig. 2), percent top-kill, year of death, and cause of death. Plot establishment began in August-September 1972 and continued through May 1974 after the population plot areas were established. First, priority was given to establishing plots in heavy, moderate, and light defoliation class areas. Four plot clusters were established in fall 1972; the remainder were located and measured before bud burst in spring 1973 so that 1972 defoliation estimates could be made. Plots in very light defoliation areas were not established until fall 1973 or early spring 1974 before bud burst because defoliation was not evident until the summer of 1973. Ultimately, 342 plots con-

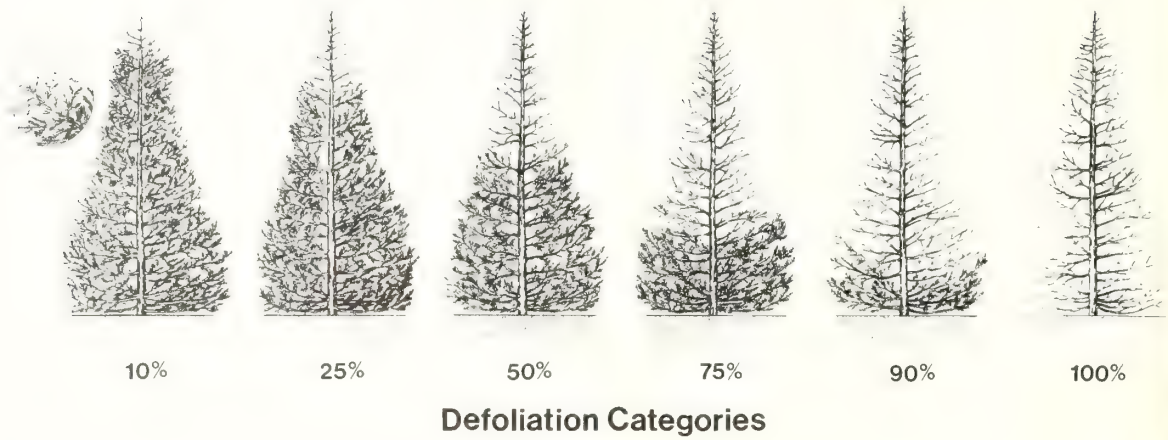



*Figure 2.--Defoliation categories used in estimates, for individual trees, of percent of crown totally defoliated, 1972-73. Inset shows partial defoliation of lower branches.*

taining 2,686 grand fir and Douglas-fir trees were established.

In other tree damage studies conducted after tussock moth outbreaks, I have noted that considerable tree mortality occurs at the height of the outbreak, but it also continues for about 4 additional years (Wickman 1963). Consequently, the plots in this study were measured twice a year for tree mortality and top-kill in the spring and fall starting in fall 1972 through 1974 to date and identify cause of mortality more precisely. Then they were measured annually each fall in 1975 and 1976.

Tussock moth feeding progresses from new to older foliage, and old foliage is usually not consumed until all new foliage has been destroyed. Partly because of a higher concentration of new foliage, defoliation occurs first on the outside of the crown and in the top of the tree and then progresses inward and downward depending on larval densities. This defoliation pattern is more pronounced in true firs than Douglas-firs but is generally similar for both species. Defoliation estimates of each plot tree were recorded as one of seven classes representative of percent of crown length totally defoliated (fig. 2).

In fall 1972 or before bud burst in 1973, individual trees on the plots were classified on the extent of defoliation caused by 1972 larval populations; again in fall 1973 or early spring 1974, they were classified for defoliation caused by 1973 larval populations. No measurable defoliation was caused by the few scattered 1974 larval populations. All estimates were made by one person, eliminating interobserver variation. The use of seven illustrated classes reduced intraobserver variation.

Cause of death during the 1972-74 examinations was assumed to be tussock moth in trees defoliated 50 percent or more if we found no evidence of bark beetles, such as larvae under the bark as high on the bole as could be reached with an axe (3 m) or woodpeckering on the upper bole, emergence holes, and pitch streaks on currently attacked trees. Cause of death in 1974 and after was easier to determine because of fading of the new growth of foliage. In both years, color of cambium was also used to help determine time of death. Brown streaks or completely brown cambium in the base indicated death, as found by Belyea (1952) in balsam fir killed by spruce budworm defoliation. In trees killed by secondary beetle attack, year of death was the year of attack.

Top-kill was estimated with the aid of binoculars each fall starting in 1974. By that time, enough foliage had recovered for us to judge whether a top was dead or just defoliated. Top-kill was assigned one of the following six classes: leader only; 1 to 10 percent; 11 to 25 percent; 26 to 50 percent; greater than 50 percent; older top-kill (this was assigned at the time of plot establishment).

## *ANALYSIS*

The tree defoliation data were summarized by the four mapped defoliation classes and tested for significant differences, among defoliation classes for both tree species and the 2 years of defoliation by analysis of variance. A t-test was also made to compare differences of defoliation of grand fir and Douglas-fir. Tree mortality and top-kill data were summarized several ways. They were tabulated by host species and by cause of death as related to individual-tree defoliation estimates. This type of summary is useful for predictive purposes and for modeling the relation between population densities and expected branch and tree defoliation and then relating defoliation to expected damage--the ultimate goal of this study.

The tree mortality data were also summarized by four defoliation classes aerially mapped by pest managers in 1972. Although mapped classes form a relatively low-resolution model, in practical terms this is the way most outbreaks are categorized. This analysis is useful for broad predictions of expected damage in the aerially mapped classes used by pest managers. Plots were also stratified by the four defoliation classes according to how they fell within clusters of plots. For instance, a moderate defoliation class was composed only of plots classified as moderate on the ground, even though in reality an aerially mapped moderate class may have been a mosaic of heavy, moderate, and light defoliation classes. Although artificial in practice, this last method of analysis is the only way the data can be compared with earlier studies in California, and it is a more accurate record of mortality, acre by acre.

Chi-square tests were made of differential mortality between grand fir and Douglas-fir by percent tree defoliation. The possible effects of species composition in the stand contributing to these differences were explored using a regression analysis. Top-kill was tabulated and summarized in a manner similar to tree mortality.

## Results and Discussion

### DEFOLIATION

Average individual-tree defoliation estimates for each of the four defoliation classes for 1972 and 1973 are presented in figure 3 for both species. Heavy areas did not receive additional defoliation of other than current foliage in 1973, even though some older foliage was available. Grand fir in moderate areas received 7-percent additional 1973 defoliation, and Douglas-fir trees in the same class averaged about 20-percent additional defoliation. Higher defoliation in 1973 was particularly noticeable for both species in previously light and very light areas; again, Douglas-fir suffered almost double the amout of defoliation as grand fir.

The average defoliation, with standard errors of the means, for each cluster of plots in each class was plotted for 1972 and 1973 estimates to show the variation within and between classes (figs. 4 and 5). The 1972 data shown in figure 4 fall into expected patterns by defoliation class. Standard errors of the mean are 10 percent or less; little spread and no overlap of mean percent defoliation occurs for the four classes. When 1973

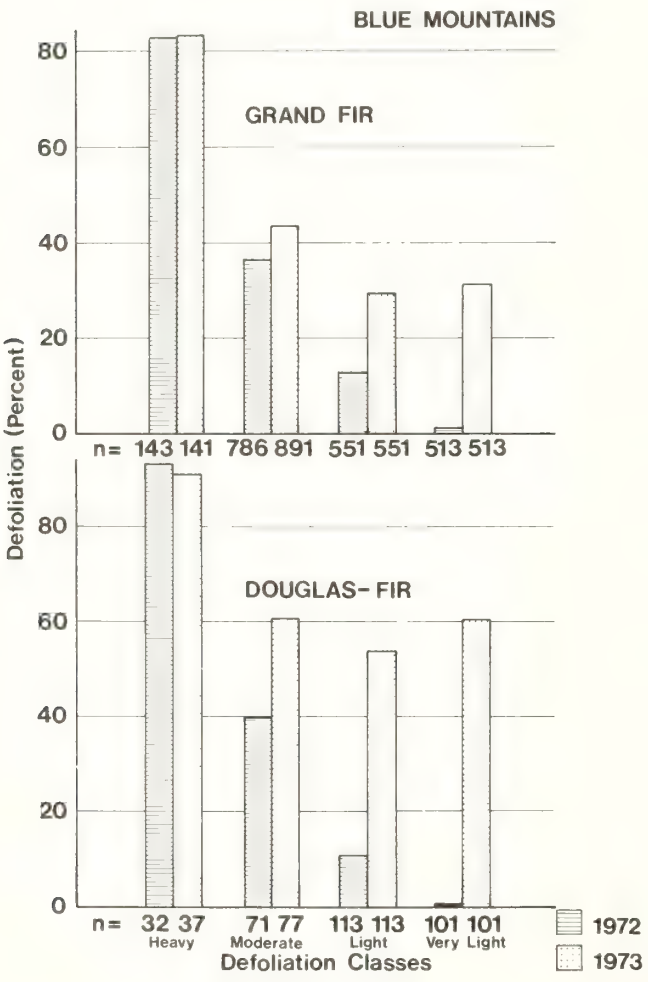



*Figure 3.--Average (weighted by number of trees in each class) 1972 and 1973 defoliation of all plot trees by 1972 defoliation classes.*

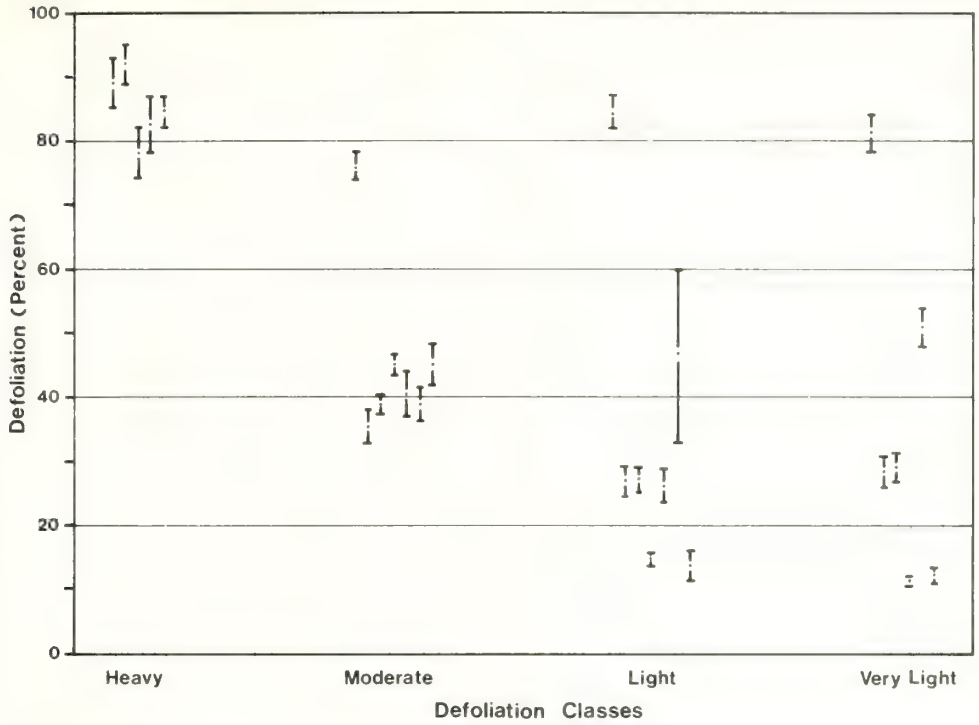



*Figure 4.--Average percent defoliation, 1972 (S.E. of replicated plot clusters).*

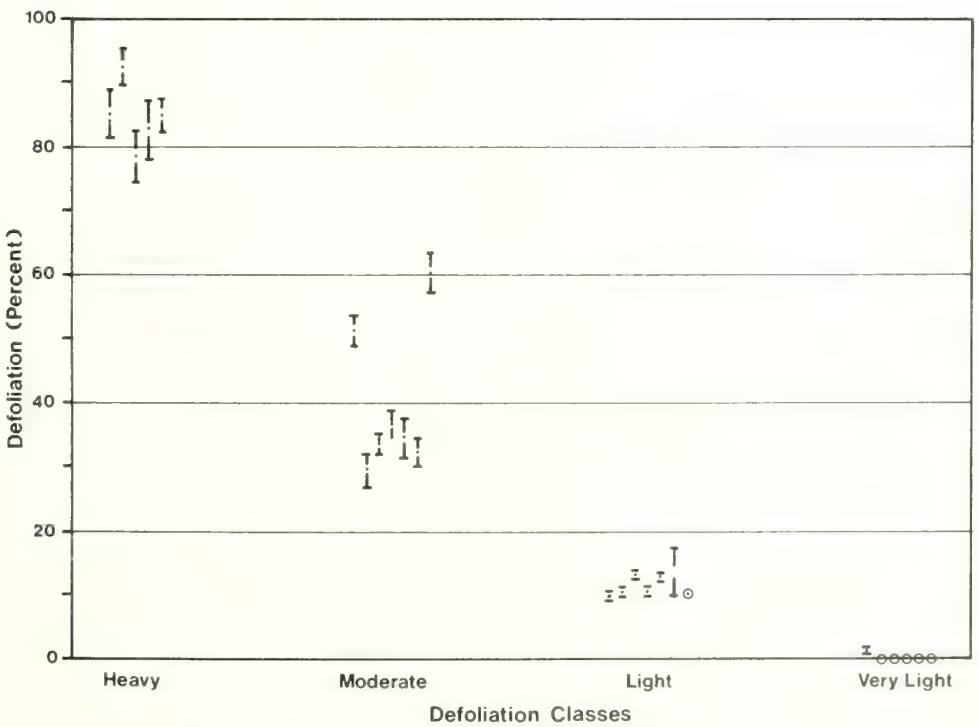



*Figure 5.--Average percent defoliation, 1973 (S.E. of replicated plot clusters).*

data are plotted in figure 5, however, the heavy and moderate class areas show practically no change from 1972 to 1973, either within replicates or between classes. Light and very light areas overlap, and both resemble the moderate defoliation class. One replicate in each of the light and very light classes reaches the moderate class, and one replicate in each class reaches the heavy defoliation class.

Next, 1972 defoliation was plotted against 1973 defoliation (fig. 6). This figure further illustrates relatively little change in the heavy and moderate classes as compared with the increased 1973 defoliation in all of the very light plot clusters and four of the light plot clusters.

These relations were explored further for the replicated plot clusters by using an analysis of variance and several t-tests on percent defoliation means to test for differences between defoliation classes and between years.2/

2/ A similar analysis was also performed where the number of trees per plot was used as a covariate to remove the variation caused by unequal numbers of trees. In all instances, the two separate analyses concurred.

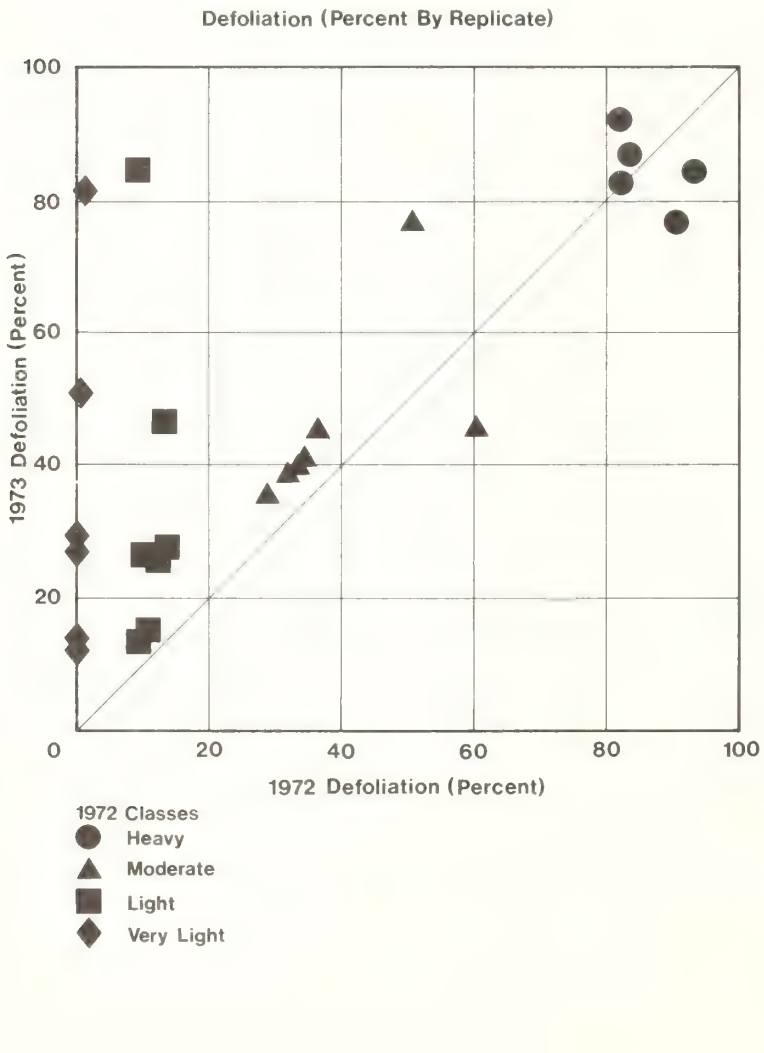



*Figure 6.--Percent defoliation in 1972 and 1973 in replicated plot clusters.*

The comparison of 1972 replicated plot defoliation means among classes for grand fir (F = 524) and Douglas-fir (F = 244) was highly significant at the .01 level. The F value for plot defoliation means in 1973 indicated that the differences between defoliation of grand fir (F = 50.5) and Douglas-fir (F = 6.92) were also highly significant at the .01 level.

I suspected that the highly significant difference among means for the four classes for both years could be caused by the high mean in the heavy class. Therefore, an analysis of variance was made comparing means of only the moderate, light, and very light classes for grand fir--to determine if the differences among those class means were significant in 1973. The F value of 7.26 was highly significant (.01 level) indicating a difference. A multiple comparison test was conducted to find out where the differences existed and, as expected, the heavy class mean was significantly greater than the other classes, and the moderate class was significantly greater than the light class at the .01 level. No other differences were significant. The same test made on Douglas-fir for 1973 defoliation means gave an F value of 1.34 and was not significant, indicating either too small a sample or much variation within moderate, light, and very light defoliation classes for this species.

The defoliation estimates and the classifying of plot clusters by defoliation class were consistent and relatively free of variation in 1972. Heavy defoliation in 1973 in some light and very light classes, however, created enough variation to obscure the original 1972 pattern of defoliation classes. Also of interest was the small amount of foliage gain in heavy class areas in 1973 (fig. 6). No additional defoliation occurred on any of the plots in 1974, even though several had enough early instar larvae to cause potential defoliation. The populations on these plots declined so rapidly that no measurable defoliation and few survivors were found by the end of the summer (Mason 1976).

Another series of tests were made to see if significant differences occurred between defoliation of grand fir and Douglas-fir. A t-test was used to compare the replicated plot, percent-defoliation means for Douglas-fir and grand fir for 1972 and 1973 (table 10, appendix). No significant difference was found in defoliation between Douglas-fir and grand fir in 1972, nor between the two species in the heavy class areas in 1973. But in the other classes in 1973, Douglas-fir suffered significantly more severe defoliation. This defoliation differential between grand fir and Douglas-fir plays an important role in the patterns of tree mortality that will be summarized in the following sections.

## *TREE MORTALITY RELATED TO DEGREE OF INDIVIDUAL-TREE DEFOLIATION*

Tree mortality related to degree of defoliation shown in figure 2 (the highest defoliation regardless of year) was estimated for individual trees (figs. 7a and 7b). Cause of death is graphed on a probit scale for mortality from defoliation alone and secondary attack by bark beetles after defoliation. For both grand fir and Douglas-fir mortality from

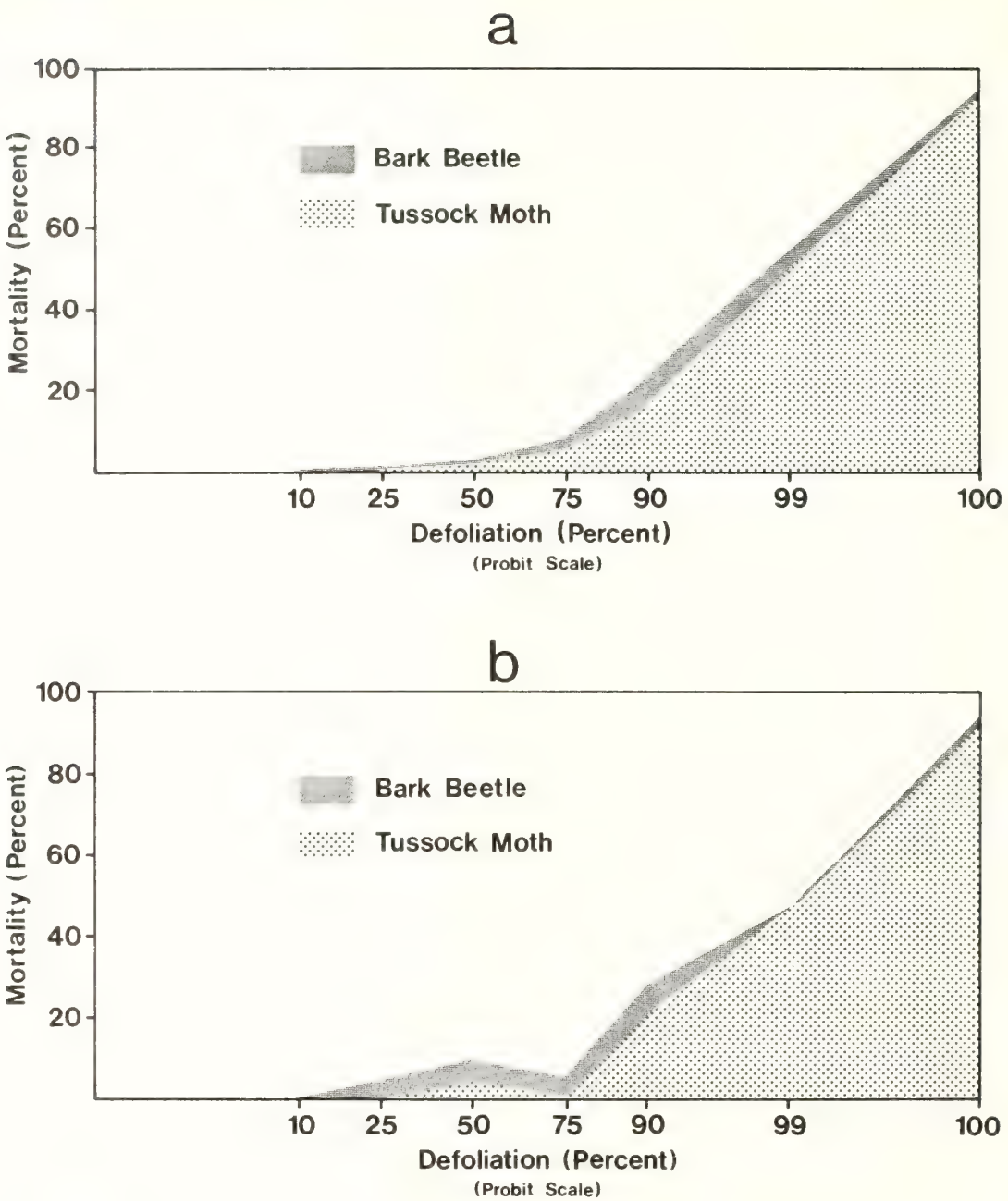



*Figure 7.--a, Percent grand fir (number) killed by tussock moth and bark beetles by individual-tree classes, 1972-1976, Blue Mountains; b, percent Douglas-fir (number) killed by tussock moth and bark beetles by individual-tree classes, 1972-1976, Blue Mountains.*

defoliation occurred only in the 50-percent or greater defoliation categories. And the 50-percent category suffered only 1-percent loss of grand fir and 4-percent loss of Douglas-fir. For both species, over 90 percent of the mortality from effects of defoliation alone occurred in trees defoliated 90 percent or greater. The discrete data for the 99-percent defoliation category was surprising. That category was improvised in the field because some defoliated trees fell between the 90 and 100 percent categories. Most of these trees had only one branch with green needles or sometimes just a few green needles, so were not truly 100-percent defoliated. In the 99-percent defoliated category, only 48 percent of the grand fir and 46 percent of the Douglas-fir succumbed, but in the 100-percent defoliation category, 93 and 92 percent, respectively, died. Combined mortality for both species as related to degree of defoliation is graphed in figure 7c and compared with mortality of white fir after an earlier California outbreak (Wickman 1963).

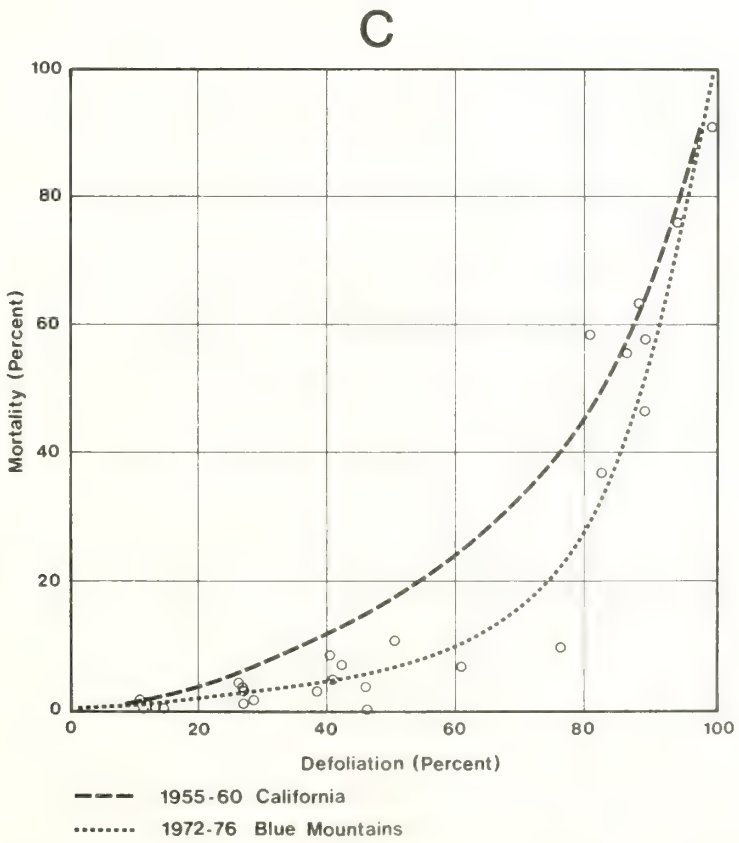



*Figure 7.--c, Total tree mortality related to degree of defoliation of white fir in California, 1956-1960, and grand fir and Douglas-fir in the Blue Mountains, 1972-1976.*

The two graphs are compared because many predictions of tree mortality since 1963 have been made based on the curve. If the 1963 data are used as a predictor of damage for this outbreak, then the deviation of 1972-1976 data from the expected may be explained by lower mortality from bark beetles in the Blue Mountains outbreak. These secondary mortality relations are discussed in some detail in the remainder of this section.

Mortality from secondary attacks by bark beetles was related to degree of defoliation, but not so strongly in Douglas-fir as in grand fir. Mortality caused by bark beetles in grand fir was distributed fairly evenly through the 75 to 100 percent categories, with the highest occurrence in the 90-percent category (7 percent). With Douglas-fir, the mortality was fairly evenly distributed through the 25- to 90-percent categories with the 90 percent again suffering slightly higher mortality (7 percent). This distribution of mortality caused by Douglas-fir beetle suggests that defoliation intensity alone was not responsible for susceptibility to secondary insect attack. No published data are available on mortality caused by Douglas-fir beetles of trees defoliated by tussock moth, but some unpublished data were located on this subject. In 1946, W. J. Buckhorn[3/] established a study of a series of 50 defoliated Douglas-fir in an area of heavy defoliation after the 1946-1947 tussock moth outbreak near Troy, Oregon. Percent defoliation was estimated for each tree to the nearest 5 percent after 1946 defoliation; then the tagged trees were reexamined annually until 1951 to determine cause of death. Defoliation intensity ranged from 5 to 95 percent with an average of 34.1 percent, similar to the average defoliation on all Douglas-fir in this study in 1972 (31.4 percent). Tree diameters averaged 21.1 inches, ranging from 10 to 36 inches. Buckhorn recorded no mortality from defoliation alone but mortality from Douglas-fir beetle started in 1947 with 14 percent killed; in 1948, 26 percent were killed and in 1949, 3 percent were killed. No additional mortality occurred the next 2 years. The mortality occurred in all defoliation classes, but over 50 percent of the total mortality occurred in trees defoliated from 5 to 35 percent. Most of the initial mortality in 1947 (5 of 7 trees), however, occurred in trees defoliated 80 to 95 percent, indicating that the Douglas-fir beetle populations may have initially developed in severely defoliated trees, and then attacked trees indiscriminately the next year before the population declined. Some evidence of similar patterns of damage by Douglas-fir beetles occurred in my study. For instance, the total mortality was distributed through most of the defoliation categories, not just the heaviest; however, mortality progressed through time as follows: 1973, 2.4 percent killed (mostly in heavy defoliation categories); 1974, 7.6 percent; 1975, 2.7 percent; and 1976, 0.4 percent. Studies of the relation of bark beetles to defoliated stands were terminated in 1976, because of the extremely widespread logging activities since 1973 around

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3/ Unpublished data on file at the Forestry Sciences Laboratory, Corvallis, Oregon.

most of the plots. Logging influences on Douglas-fir beetle populations--if the results of earlier studies on this relation are relevant here--are probably masking the effects of tussock moth defoliation (Lejeune et al. 1961; Rudinsky 1962; Johnson and Belluschi 1969).

Losses in grand fir from fir engraver beetle, *Scolytus ventralis* Lec., were apparently not as great as they were in white fir in two California outbreaks. There, after a 1956 infestation, three-quarters of the tree mortality in 1957 was because of fir engraver beetles and the roundheaded fir borer, *Tetropium abietis* Fall. (Wickman 1958). In an earlier outbreak in California (Mammoth Lakes 1938), 12 percent of the white fir were killed by defoliation alone and 17.1 percent by secondary attack by bark beetles (Wickman 1963). Apparently, therefore, in this outbreak fir engraver beetles did not reach a high level.

Many of the trees rated as killed by defoliation in 1972 and 1973 had attacks, but little or no brood production because of sour phloem with very high water content, a condition also found by Wright and Berryman.[4/] Conversely, some trees that appeared to have good bark beetle brood production may have ultimately died from the effects of defoliation alone. Exact cause of death, immediately after defoliation, is difficult to determine because defoliation effects and secondary insect attacks may be so strongly related. The important fact is that trees over 90-percent defoliated have a high probability of dying, and mortality probably occurs whether bark beetles attack or not, thus explaining the similarity of total mortality in several past outbreaks.

From these data and Buckhorn's, only trees severely defoliated (80-percent or more) appear to have a high probability of being attacked by bark beetles the first 1 or 2 years after defoliation takes place, but then continued bark beetle activity is dependent on other environmental factors.

The aspect of importance with bark beetles is identifying the cause and timing of a population build-up capable of killing healthy as well as slightly weakened trees. Because several studies now have shown a great deal of variation in postoutbreak tussock moth and bark beetle populations, recent definitive studies may identify this threat more precisely.[5/] An understanding of the population dynamics of the bark beetles, plus the influences of logging and subnormal precipitation will have to be considered, along with the presence of trees weakened by defoliation.

Undesignated mortality, such as wind and snow breakage, shading of suppressed trees, and unknown (presumed to be disease-caused), are summarized in table 1. Note that Douglas-fir suffered

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[4/] Wright, L. C., and A. A. Berryman. Host resistance to the fir engraver beetle: Effect of defoliation on moisture stress of *Abies grandis* (Unpublished report to USDA Expanded Douglas-fir Tussock Moth Research and Development Program).

[5/] Personal communication, Alan A. Berryman, Washington State University, Pullman, Washington.

Table 1--*Percent mortality by other causes for each tree defoliation category*

| Species | Percent defoliation | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 25 | 50 | 75 | 90 | 99 | 100 |
| Grand fir | 3 | 1 | 2 | 2 | 5 | 7 | 1 |
| Douglas-fir | 7 | 8 | 1 | 0 | 10 | 15 | 1 |

double the mortality of grand fir by these other causes. Most of this mortality was caused by wind and snow breakage and was distributed throughout the study period. Some or all of the mortality from unknown causes and suppression could have been related to defoliation, but we had no way of determining this relation.

## *TREE MORTALITY RELATED TO D.B.H.*

Mortality of grand fir and Douglas-fir by diameter class was summarized by each tree on all plots and graphed to show the distribution of mortality caused by defoliation alone and bark beetles (fig. 8). For grand fir, the mortality is fairly evenly distributed in all d.b.h. classes except no mortality from bark beetles occurred in the 1- to 6-inch class.

In an earlier study in California white fir (Wickman 1963), I found that the mortality from defoliation alone was not evenly distributed; most of it occurred in trees 2 to 10 inches d.b.h. In that study, mortality from defoliation and bark beetles of

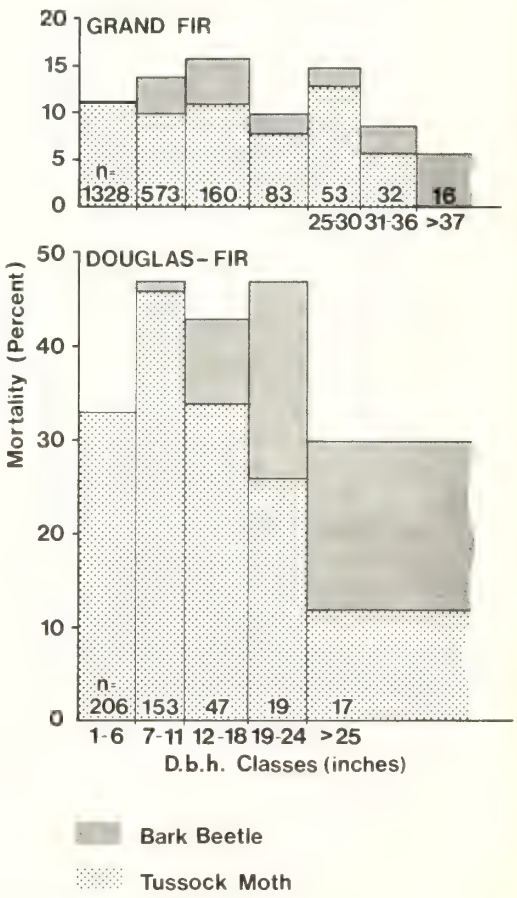


*Figure 8.--Percent mortality by species, diameter class, and cause. 1972-1976, Blue Mountains.*

saplings and small poles averaged 27.4 percent, and sawtimber mortality averaged 13.8 percent. Grand fir in the Blue Mountains outbreak did not suffer such a pattern of mortality, but this may have been in part, because of lower fir engraver populations. In the Blue Mountains outbreak, all 16 of the plot trees larger than 36 inches d.b.h. that died were killed by bark beetles.

Douglas-fir mortality from defoliation alone was concentrated in the smaller trees, and mortality from bark beetles in the larger trees--and at a higher level than secondary mortality of grand fir. Most mortality caused by Douglas-fir beetle was in trees 12-inch d.b.h. or larger, and trees over 20-inch d.b.h. were the most susceptible.

### *TREE MORTALITY RELATED TO CROWN CLASS*

Mortality of grand fir and Douglas-fir by crown class was summarized using individual trees on all plots. A distribution of percent mortality for both species by crown class is given in table 2. This summary shows an apparent trend of mortality in Douglas-fir killed by defoliation. Dominant and codominant trees have almost 50 percent more mortality than intermediate and suppressed trees. All four crown classes for grand fir suffered nearly equal amounts of mortality from defoliation alone. But mortality from bark beetles occurred mainly in dominant and codominant trees for both species.

Crown classes are normally related to d.b.h. class. Most trees over 12-inch d.b.h. are dominant or codominant, and most trees smaller than 12 inches are intermediate or suppressed. This distribution is related to the distribution of mortality for both species shown in figure 8.

### *TREE MORTALITY IN THE FOUR DEFOLIATION CLASSES*

The next two summaries and analyses are stratified two different ways.

Table 2--*Percent grand fir and Douglas-fir mortality by crown class and cause*

| Crown class | Species | Mortality | |
|---|---|---|---|
| | | Defoliation | Bark beetles |
| Dominant | GF | 11.8 | 5.4 |
| | DF | 46.7 | 7.8 |
| Codominant | GF | 11.0 | 4.8 |
| | DF | 44.2 | 6.7 |
| Intermediate | GF | 11.6 | 1.6 |
| | DF | 25.8 | 0 |
| Suppressed | GF | 9.7 | 0.1 |
| | DF | 30.5 | 0 |

*1972 mapped defoliation classes.*--The percent stand (volume and number) mortality for each year, defoliation class, and tree species is shown in table 11, appendix. This includes mortality from both defoliation and bark beetles. This summary excludes most back country plots because they did not fall in the replicated population plot design. Two clusters of heavily defoliated plots from the back country were used, however, to provide enough data for analysis of the heavy class.

Plot data are stratified by the broad aerially mapped classes. In other words, any mapped class could be expected to contain a mosaic or mixture of several defoliation classes. The total mortality for each defoliation class in this arrangement is shown in figure 9. It indicates highest mortality occurred in the heavy defoliation class areas with 38.6 percent of the stand (number) and 45.3 percent of the volume killed by the outbreak.

*Individual-plot defoliation classes.*--These data are from the same plots used in the previous section. For this analysis, however, each plot was stratified strictly by the average plot defoliation into one of the four classes (table 12, appendix).

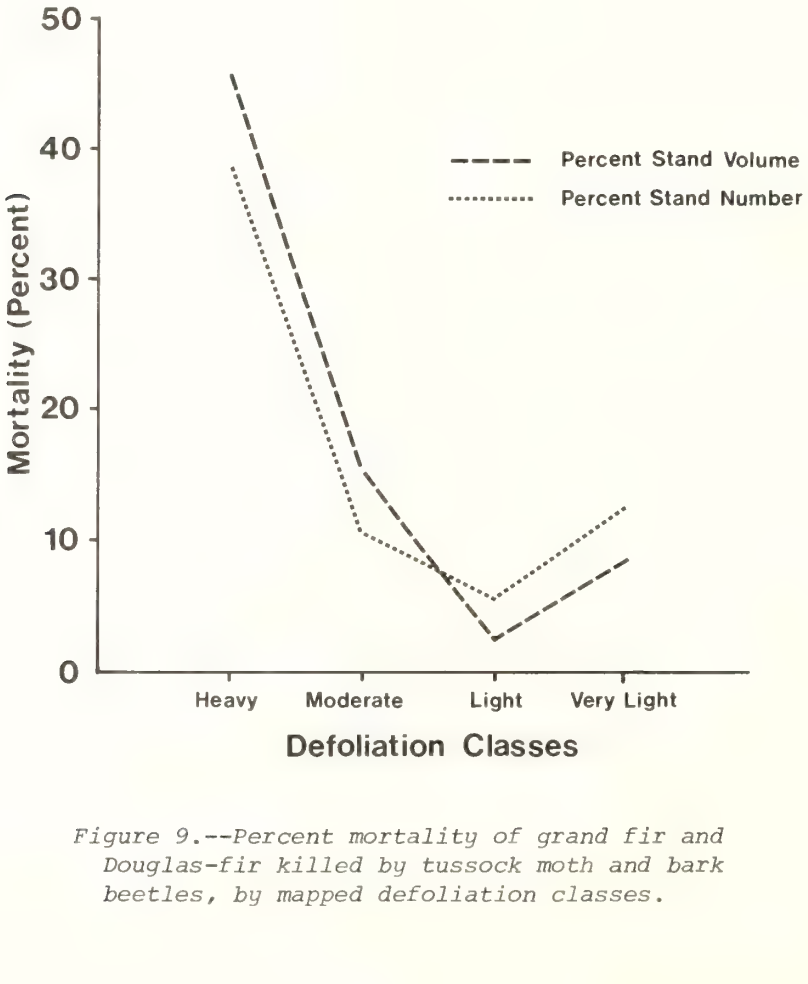


*Figure 9.--Percent mortality of grand fir and Douglas-fir killed by tussock moth and bark beetles, by mapped defoliation classes.*

That is, each plot within a cluster is classed according to its individual defoliation level in 1972. Therefore, the heavy class is composed of only heavy class plots, moderate class is composed only of moderate class plots, and so on. More plots were included in this analysis because all back country plots were used. A comparison of tables 11 and 12, appendix, shows a shift in the number of heavy class plots to the moderate and light classes and some additional redistribution of plots from the mapped stratification of plot clusters to the individual plot stratification. This occurs because of the more precise classification of individual plots in this summary. The change of plot totals for each defoliation class from the mapped to the individual-plot classification is shown in table 3. For instance, of 76 heavy defoliation class plots in the mapped stratification, 54 percent remained in the heavy class using the individual-plot stratification, 36 percent were actually in the moderate class, and 10 percent in the light class. Another large discrepancy occurred in the change of 42 percent of the mapped light class plots to moderate class plots using the individual-plot stratification.

Total mortality graphed by defoliation class in this analysis (fig. 10) now shows more precise breakdown by defoliation class with 72-percent mortality (number) in the heavy class, 5.2-percent in the moderate class, 6.3-percent in the light class, and 11.1-percent in the very light class. Only the light and very light classes are similar for both analyses.

*Cumulative annual mortality compared on mapped versus individual-plot defoliatin classes.*-- The mortality trends are similar for data analysis by both methods of plot stratification (illustrated by figs. 11a-11d), but the totals for most classes are different. Graphs 11a and 11b show the cumulative mortality for plots in the mapped area and 11c and 11d for the ground-classed plots. Again, as in figure 10, graphs 11c and 11d reflect a better correlation of mortality with defoliation class within plot clusters. Data for graphs 11a and 11b may be more easily estimated and extrapolated using aerial mapping, but they are not an accurate accounting

Table 3--*Breakdown of plot numbers and changes according to method of analysis*

| Mapped defoliation class[1] | No. plots | Breakdown by individual-plot defoliation class[2] | | | |
|---|---|---|---|---|---|
| | | Heavy | Moderate | Light | Very light |
| Heavy | 76 | 41(54%) | 27(36%) | 8(10%) | 0(0%) |
| Moderate | 86 | 6(7%) | 76(88%) | 4(5%) | 0(0%) |
| Light | 60 | 0(0%) | 25(42%) | 35(58%) | 0(0%) |
| Very light | 63 | 0(0%) | 0(0%) | 4(6%) | 59(94%) |

[1] Total number of plots by mapped defoliation class = 285.

[2] Total number of plots by individual-plot defoliation class = 342.

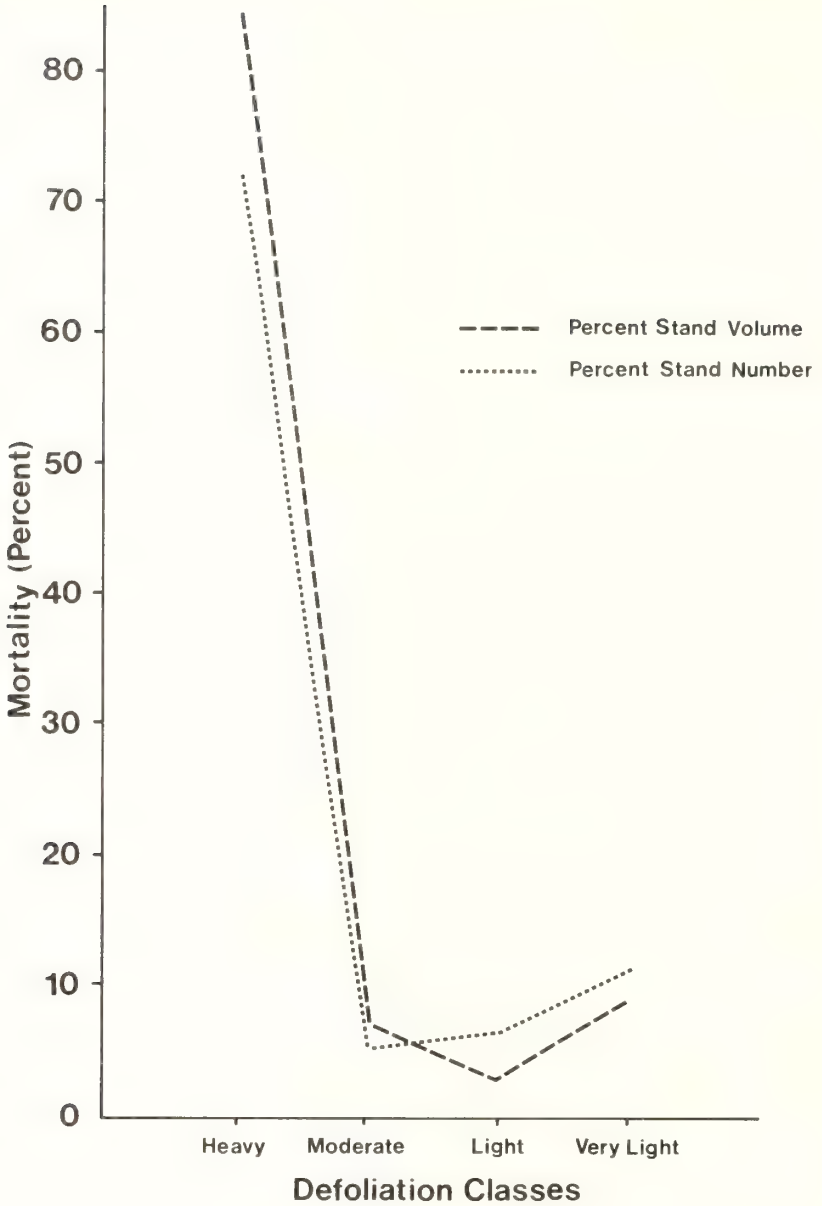


*Figure 10.--Percent mortality of grand fir and Douglas-fir killed by tussock moth and bark beetles, by individual-plot defoliation classes.*

of the tree mortality for the manager who wants information acre by acre. The differences in the heavy and moderate classes in the two analyses must be considered in making predictions for management purposes.

Table 4 which summarizes averages and standard errors for mortality in each defoliation class stratified by mapped and individual defoliation classes, indicates greater variation when heavy and moderate defoliation

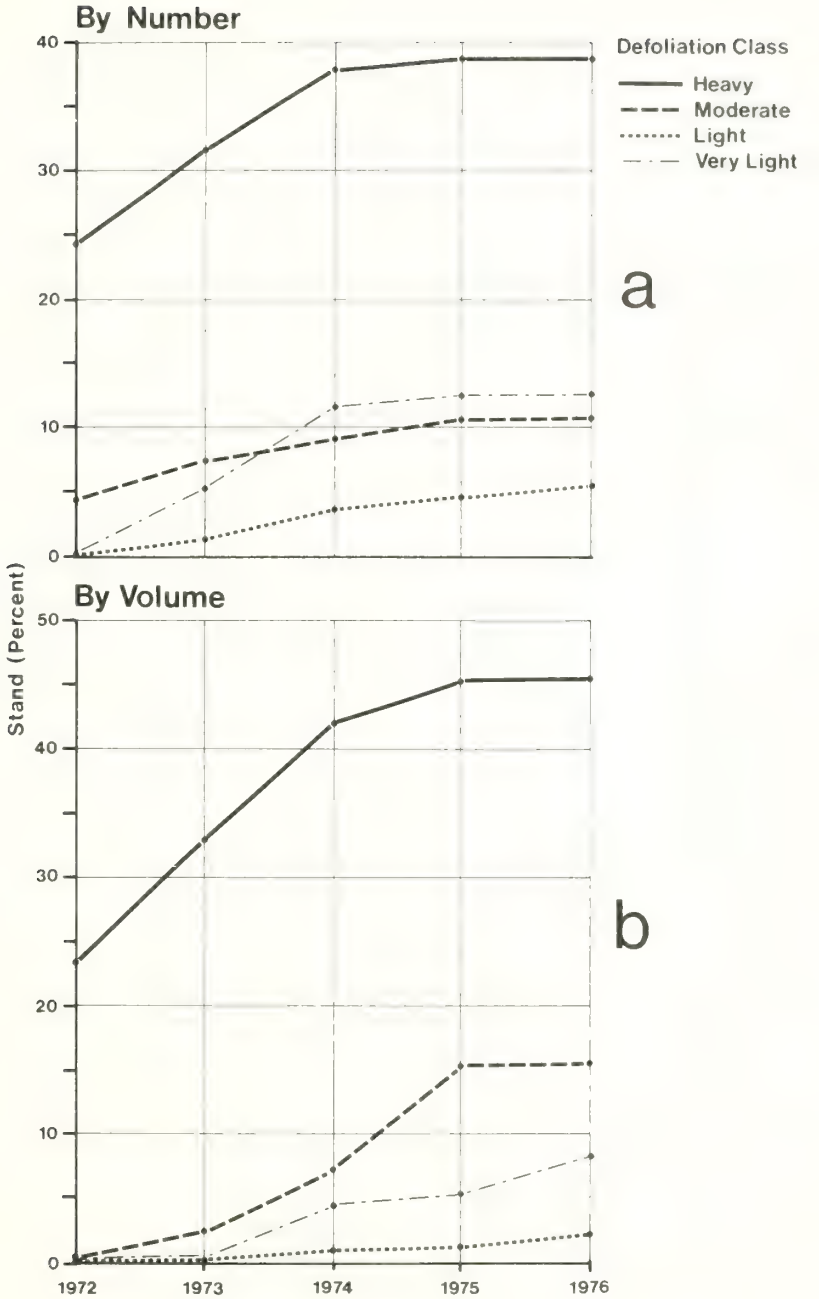


*Figure 11.--a, Cumulative percent stand (number) killed by tussock moth and bark beetles for each mapped plot defoliation class; b, cumulative percent stand (volume) killed by tussock moth and bark beetles for each mapped plot defoliation class.*

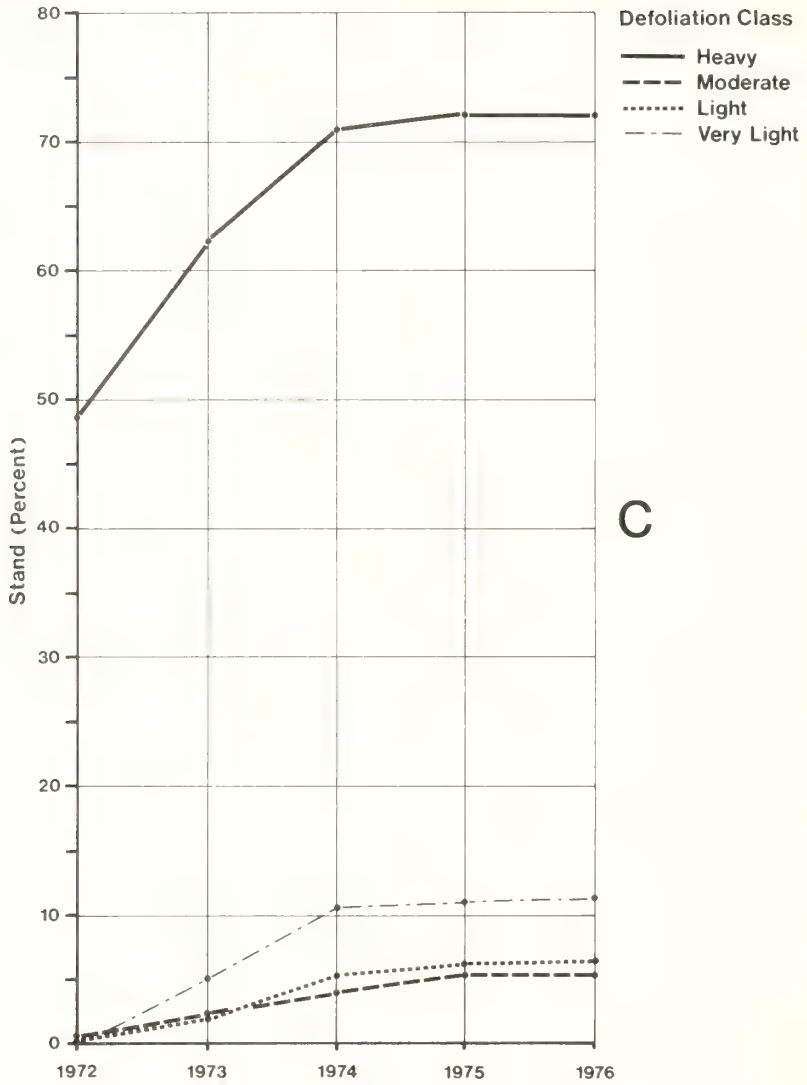


*Figure 11.--c, Cumulative percent stand (number) killed by tussock moth and bark beetles for each individual defoliation class.*

plots are stratified by mapped classes. The standard error of the means reach almost 50 percent by this analysis, compared to about 10 percent of the mean for heavy and moderate classes in the individual-plot stratification. Little change occurs for plots in the light and very light classes. The higher variation for these two classes, for both forms of analysis, was the result of the range of none to very heavy mortality on some plots after 1973 defoliation.

From these data, we can see problems and sources of error in making damage predictions based solely on mapped classes. Within

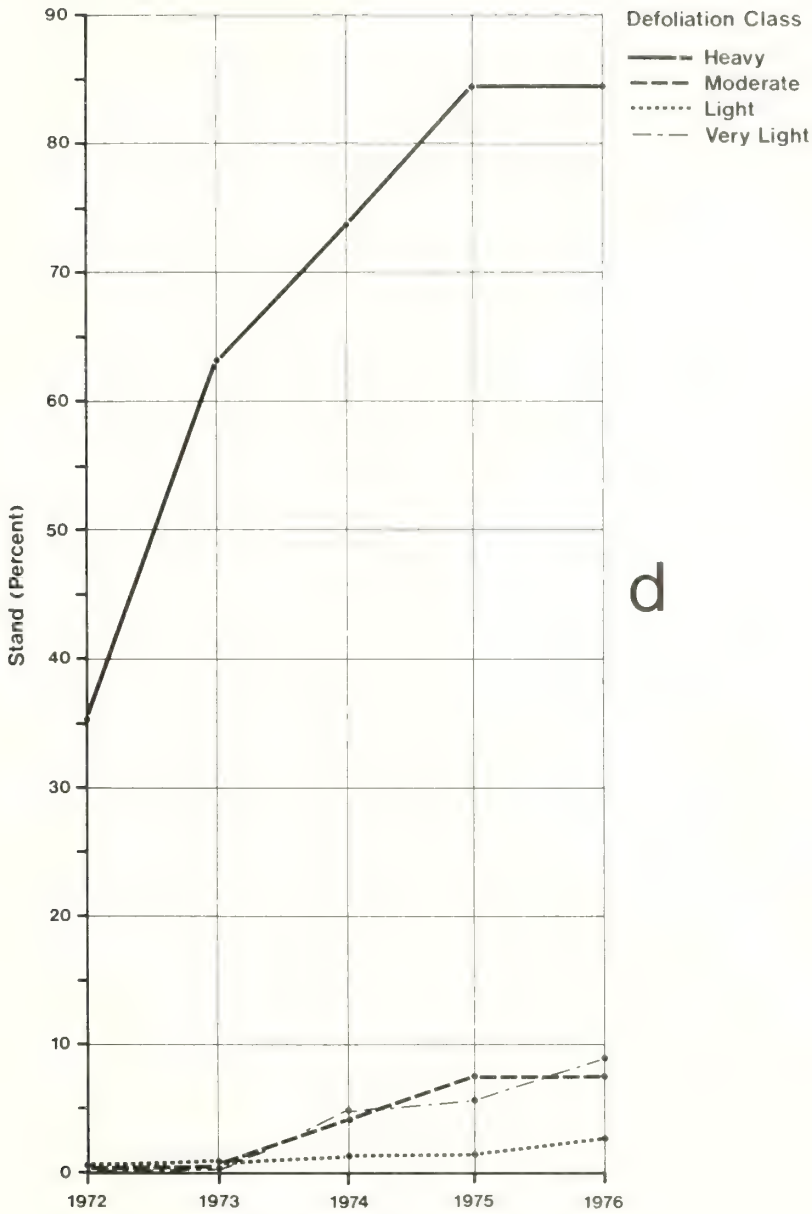


*Figure 11.--d, Cumulative percent stand (volume) killed by tussock moth and bark beetles for each individual defoliation class.*

each mapped class is a mixture of several levels of defoliation, because tussock moth populations are not evenly distributed. They tend to be aggregated at higher levels in scattered clumps, and defoliation patterns reflect this population distribution. Therefore, the analysis by each individual-plot defoliation class is more accurate, in terms of what is happening acre by acre;

Table 4--*Average mortality and standard error of plots stratified by mapped and individual-plot defoliation classes*

| Defoliation class | Mapped defoliation classes | | Individual-plot defoliation class | |
|---|---|---|---|---|
| | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. |
| Heavy | 38.6 | 16.8 | 72.0 | 6.1 |
| Moderate | 10.6 | 4.8 | 5.2 | 0.9 |
| Light | 5.3 | 2.8 | 6.3 | 3.5 |
| Very light | 12.6 | 9.0 | 11.1 | 9.0 |

but the technique is less practical for a pest manager to use if he relies mostly on aerial mapping. Ideally, if predictions of damage are to be made based on defoliation early in an outbreak, they should combine aerial mapping with some ground sampling to determine the true loss per acre for defoliation classes as well as the total number of acres. Aerial mapping tended to overestimate expected damage on heavy defoliation class areas because the mapped classes, although actually a mixture of several classes, are treated as a single homogeneous class and mortality predicted as such.

This problem is also evident when data from the Blue Mountains outbreak are compared with tree mortality in past outbreaks. Damage classes used from year to year and area to area must be similar before data can be meaningfully compared. Mortality recorded for the heavy defoliation area in the Stowe Reservoir infestation in California were comparable to those of the heavy defoliated plots in this study (83.9 percent in California compared with 72 percent here), but the mortality reported for heavily defoliated areas in two other California outbreaks are not comparable because the classification of "heavy" defoliation was dissimilar.

## *MORTALITY RELATED TO YEARS OF DEFOLIATION*

The graphed mortality data have shown a trend of mortality for each of the four defoliation classes regardless of the method of analysis. The heavy defoliation class areas suffered the most severe mortality, and most of it occurred in 1972 and 1973. When mortality rates by years (fig. 11) are compared with the average defoliation levels in each class for 1972-1973 (fig. 3), no increased defoliation occurred in the heavy class areas in 1973, and most of the mortality occurred in 1972. The data imply that the most severe outbreak mortality in terms of percent loss in the heavy defoliation class was directly related to 1972 defoliation. Some light and very light class areas suffered enough defoliation in 1973 to cause tree mortality, but the average total mortality for the light and very light class areas was not nearly as high as it was on the heavy class areas

in 1972. The moderate class areas fall somewhat between these two, but they also had a relatively low total mortality.

Several analyses were made to illustrate the differential effect of 1972 and 1973 defoliation and the additive effects of two consecutive years of defoliation. To do this, we used trees from some very light class plots and a few light class plots, which had little or no 1972 defoliation but very heavy 1973 defoliation, to show mortality caused by the 1973 defoliation. These data were then compared with 1972 mortality for trees defoliated 50, 75, 90, 99, and 100 percent from heavy class areas (table 5). Table 5 includes mortality occurring the same year of defoliation (1972 mortality for 1972 defoliation and 1973 for 1973 defoliation) and total mortality in 1976 for both years of defoliation, because mortality from severe defoliation actually continues for several years after the year of defoliation. Much of the new foliage on heavy class areas was defoliated to various degrees in 1973, so some cumulative effects were present which defoliated areas in 1973 did not have. The table indicates more mortality occurring after 1972 defoliation than after 1973 defoliation in all five defoliation categories (with two exceptions).

The effects of cumulative defoliation in 1972 and 1973 are summarized in table 6. The upper right quadrant of the table (percent mortality both Douglas-fir and grand fir) reading from left to right on the top row shows 0.68 percent

Table 5--*Grand fir and Douglas-fir mortality resulting from 1972 defoliation (heavy class areas) and 1973 defoliation (very light areas)*

| efoliation category | Sample trees | | | | Mortality (defoliation and bark beetles) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1972 defoliation | | | | 1973 defoliation | | | |
| | 1972 defoliation | | 1973 defoliation | | Died 1972 | | Total 1976 | | Died 1973 | | Total 1976 | |
| | GF | DF | GF | DF | GF | DF | GF | DF | GF | DF | GF | DF |
| Percent | Number | | | | Percent | | | | | | | |
| 50 | 255 | 23 | 135 | 47 | 0 | 0 | 3.9 | 13.0 | 0 | 0 | 3.7 | 4.3 |
| 75 | 90 | 11 | 35 | 27 | 0 | 0 | 15.6 | 18.2 | 2.9 | 0 | 5.7 | 3.7 |
| 90 | 115 | 21 | 47 | 22 | 3.5 | 4.8 | 49.6 | 61.9 | 0 | 0 | 12.8 | 27.3 |
| 99 | 6 | 1 | 24 | 14 | 16.7 | 0 | 50.0 | 100 | 8.3 | 14.3 | 62.5 | 35.7 |
| 100 | 126 | 113 | 29 | 28 | 84.9 | 75.2 | 97.6 | 99.1 | 62.1 | 50.0 | 89.7 | 92.9 |

Summary of 90, 99, and 100 percent categories combined.

| Species | Sample trees | | Mortality in year of defoliation | | Total mortality | |
|---|---|---|---|---|---|---|
| | 1972 | 1973 | 1972 | 1973 | 1972 | 1973 |
| | Number | | Percent | | | |
| Grand fir | 247 | 100 | 45.3 | 20.0 | 74.1 | 47.0 |
| Douglas-fir | 135 | 64 | 63.7 | 25.0 | 85.9 | 57.8 |

Table 6--*Mortality based on trees defoliated in both 1972 and 1973 (effect of cumulative defoliation)*

| Percent defoliation 1972 | Total trees<br>Percent defoliation 1973 | | | | | Percent mortality (both Douglas-fir and grand fir)<br>Percent defoliation 1973 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 75 | 90 | 99 | 100 | 50 | 75 | 90 | 99 | 100 |
| 50 | 147 | 43 | 26 | 7 | 3 | 0.68 | 6.98 | 19.23 | 14.29 | 66.7 |
| 75 | 25 | 30 | 22 | 7 | 2 | 4.0 | 16.7 | 27.27 | 28.57 | 50 |
| 90 | 8 | 12 | 58 | 24 | 20 | 12.5 | 2.5 | 44.83 | 66.7 | 100 |
| 99 | -- | -- | -- | 2 | 2 | -- | -- | -- | 100 | 100 |
| 100 | -- | -- | 3 | 7 | 9 | -- | -- | 100 | 85.71 | 100 |

| Percent defoliation 1972 | Percent mortality (Douglas-fir)<br>Percent defoliation 1973 | | | | | Percent mortality (grand fir)<br>Percent defoliation 1973 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 75 | 90 | 99 | 100 | 50 | 75 | 90 | 99 | 100 |
| 50 | 8.3 | 0.0 | 20.0 | 50.0 | -- | 0.0 | 7.3 | 19.0 | 0.0 | 66.7 |
| 75 | 0.0 | 0.0 | 0.0 | 50 | 100 | 4.2 | 18.5 | 33.3 | 20.0 | 0.0 |
| 90 | 0.0 | 0.0 | 60 | 66.7 | 100 | 14.3 | 27.3 | 43.4 | 66.7 | 100 |
| 99 | -- | -- | -- | -- | 100 | -- | -- | -- | 100 | 100 |
| 100 | -- | -- | -- | 100 | 100 | -- | -- | 100 | 83.3 | 100 |

mortality of trees defoliated 50 percent in 1972 and 50 percent or no change in 1973; 6.98-percent mortality for trees defoliated 50 percent in 1972 and 75 percent (or an additional 25 percent) in 1973; 66.7-percent mortality for trees defoliated 50 percent and 100 percent; and so on.

These data illustrate some additive effect of defoliation, with mortality increasing with increasing amounts of defoliation the second year.

### *DIFFERENTIAL MORTALITY BETWEEN GRAND FIR AND DOUGLAS-FIR*

When mortality data are summarized by tree species, Douglas-fir suffers proportionally higher amounts. This relation can be traced back to figure 3 which shows Douglas-fir consistently suffered higher levels of defoliation in 1973 than did grand fir. And table 5 indicated that Douglas-fir had an apparently higher level of mortality after 1973 defoliation and in 1976. This was most likely because of higher secondary mortality caused by bark beetles; direct mortality (caused by defoliation alone) was similar for both species.

This differential mortality is also shown in figure 12. In these graphs, mortality of Douglas-fir almost equals that of grand fir even though Douglas-fir averaged only 20 percent of the stand.[6/] Looked at another

[6/] Bolsinger and Berger (1975), in a report on the timber resources of the entire Blue Mountains area, state Douglas-fir accounts for 20 percent of the volume and true firs 19 percent. Most of our plots were concentrated in true fir stands where Douglas-fir occurred mainly as a minor component.

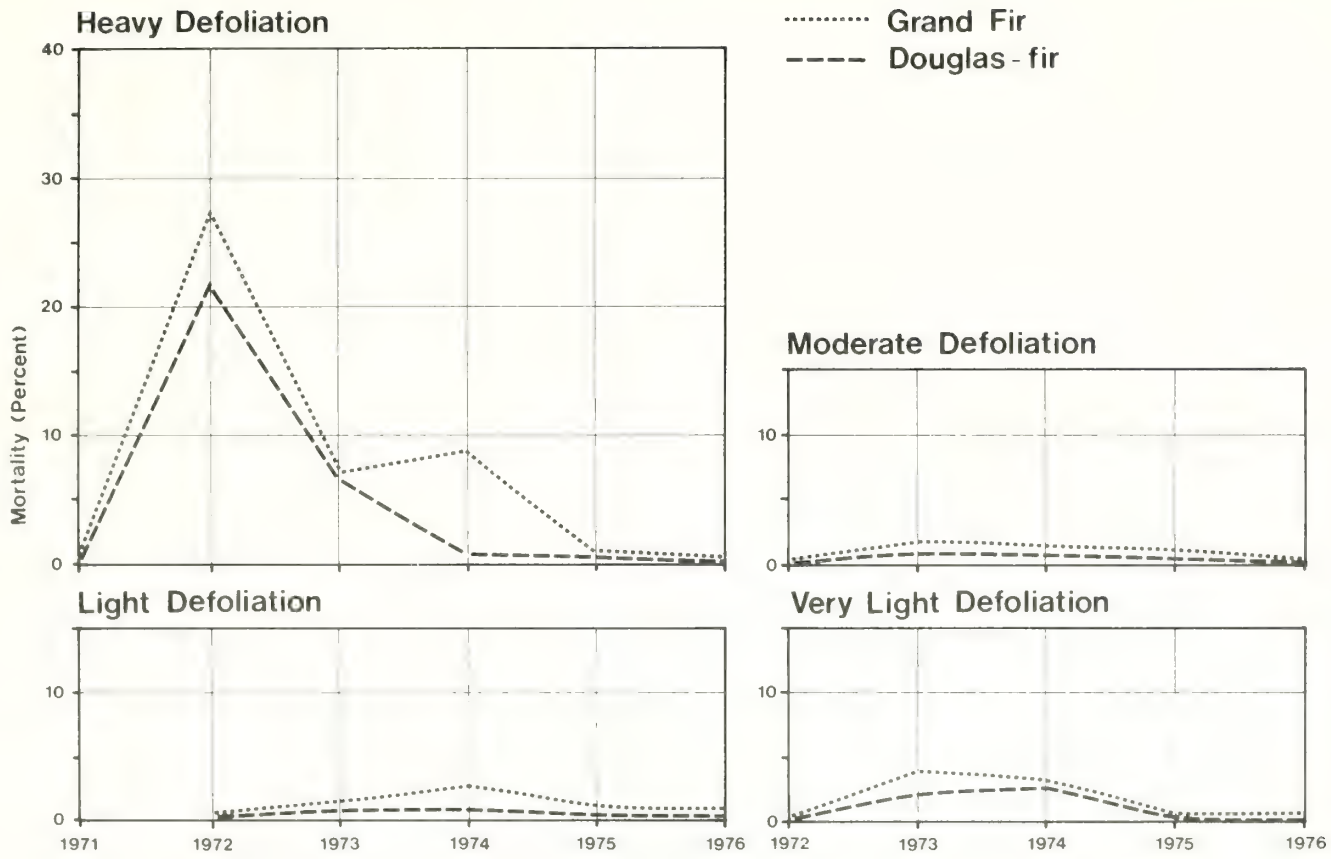


*Figure 12.--Percent stand (number) killed by tussock moth and bark beetles, 1972-1976.*

way (table 7), when total mortality is compared by species, Douglas-fir mortality surpasses that of grand fir in all four defoliation classes and by all causes.

We also compared mortality of Douglas-fir and grand fir in relation to defoliation. If mortality rates differed, then perhaps Douglas-fir was more susceptible to death after the same level of defoliation. The data were analyzed with $\chi^2$ test (shown in table 13, appendix) for four tree-defoliation categories.

The probability that $\chi^2 \geq 2.25 \simeq .66$; therefore, the hypothesis of independence was not rejected; examination of the data in table 13, appendix, discloses that mortality vectors for the two species are not detectably different. This implies that Douglas-fir is not more susceptible to mortality from the same level of defoliation, but rather the species is more susceptible to defoliation. Some feeding behavior implications may influence this defoliation relation Mason (1976) has mentioned that forest composition may have influenced the intraseason rate of larval population survival. The percent of Douglas-fir in a stand

Table 7--*Summary of tree mortality and survivors by individual-plot defoliation class and cause, 1972-1976*
(Percent mortality-number)

| Cause of mortality | Defoliation class | | | |
|---|---|---|---|---|
| | Heavy | Moderate | Light | Very light |
| GRAND FIR | | | | |
| Killed by tussock moth | 63 | 3 | 3 | 6 |
| Killed by beetles[1/] | 4 | 1 | 2 | 2 |
| Survivors | 33 | 96 | 95 | 92 |
| Other mortality | 6 | 5 | 5 | 5 |
| Current percent green stand (1976) | 27 | 91 | 90 | 87 |
| DOUGLAS-FIR | | | | |
| Killed by tussock moth | 84 | 9 | 11 | 24 |
| Killed by beetles[2/] | 1 | 9 | 1 | 3 |
| Survivors | 15 | 82 | 88 | 73 |
| Other mortality | 9 | 13 | 15 | 6 |
| Current percent green stand (1976) | 6 | 69 | 73 | 67 |

[1/] *Scolytus ventralis* and *Tetropium abietis*.

[2/] *Dendroctonus pseudotsugae*.

may slow population decline. Laboratory studies using larvae and foliage from our study areas in 1973 also suggested differential larval feeding behavior on Douglas-fir and grand fir (Beckwith 1976). This relation is being pursued by Beckwith[7/] with increasing evidence of differences in feeding behavior and needle consumption rates on the two species.

### *THE ASSOCIATION OF DOUGLAS-FIR AND STAND MORTALITY*

To determine if the amount of Douglas-fir in the stand affected combined mortality of grand fir and Douglas-fir, we stratified all the plots by percent Douglas-fir in each plot stand and found the following relation:

| Percent Douglas-fir | 0-10 | 11-25 | 26-50 | >50 |
|---|---|---|---|---|
| Percent mortality of Douglas-fir & grand fir | 13.9 | 16.3 | 14.5 | 39 |

This analysis showed no significant relation until stands contained over 50 percent Douglas-fir; then, the percent stand mortality more than doubled. When the plot data stratified by mapped classes of percent Douglas-fir in the stand and percent mortality were graphed, a relation of differential mortality related to stand composition became apparent (fig. 18, appendix). A regression analysis showed a positive relation with an $r^2$ value of .35, significant at the .05 level, for light and very light class plots (1973 defoliation only) and an $r^2$ of .37, significant at the .01 level, for all four classes and both years of defoliation. The only plots suffering tree mortality from 1973 defoliation alone were light and very light class plots with a high proportion of Douglas-fir. The relations, though not strong, are intriguing. One interpretation could be that the percent Douglas-fir in the stand is an indicator of an environmental gradient; e.g. more Douglas-fir indicates a drier site, a drier site suffers higher tree mortality.

In the Blue Mountains of Oregon and Washington, the stand composition in terms of proportion of Douglas-fir may have an important influence on the behavior of populations and levels of tree damage. Other studies and analysis in progress may help clarify this relation.

### *TOP-KILL*

Heavy defoliation by the Douglas-fir tussock moth is known to cause top-kill in white fir in California (Wickman 1963). No studies have been published of top-kill in other host species and in other areas. The top-kill damage was examined carefully and continuously through the course of this outbreak and the results are summarized similarly to the tree-mortality data. The top-kill summaries that follow are based on percent of total trees alive in 1976 except for the analysis of the relation of susceptibility of top-killed trees to mortality caused by bark beetle.

*Related to individual-tree defoliation categories.*--Five top-kill classes were compared

7/ Personal communication, J. C. Beckwith, Forestry Sciences Laboratory, Corvallis, Oregon.

for each of six defoliation categories (table 14, appendix). The most severe top-kill occurred in the trees suffering highest amounts of defoliation, and leader damage was the most common class of top-kill (figs. 13a and 13b). Trees with 1 to

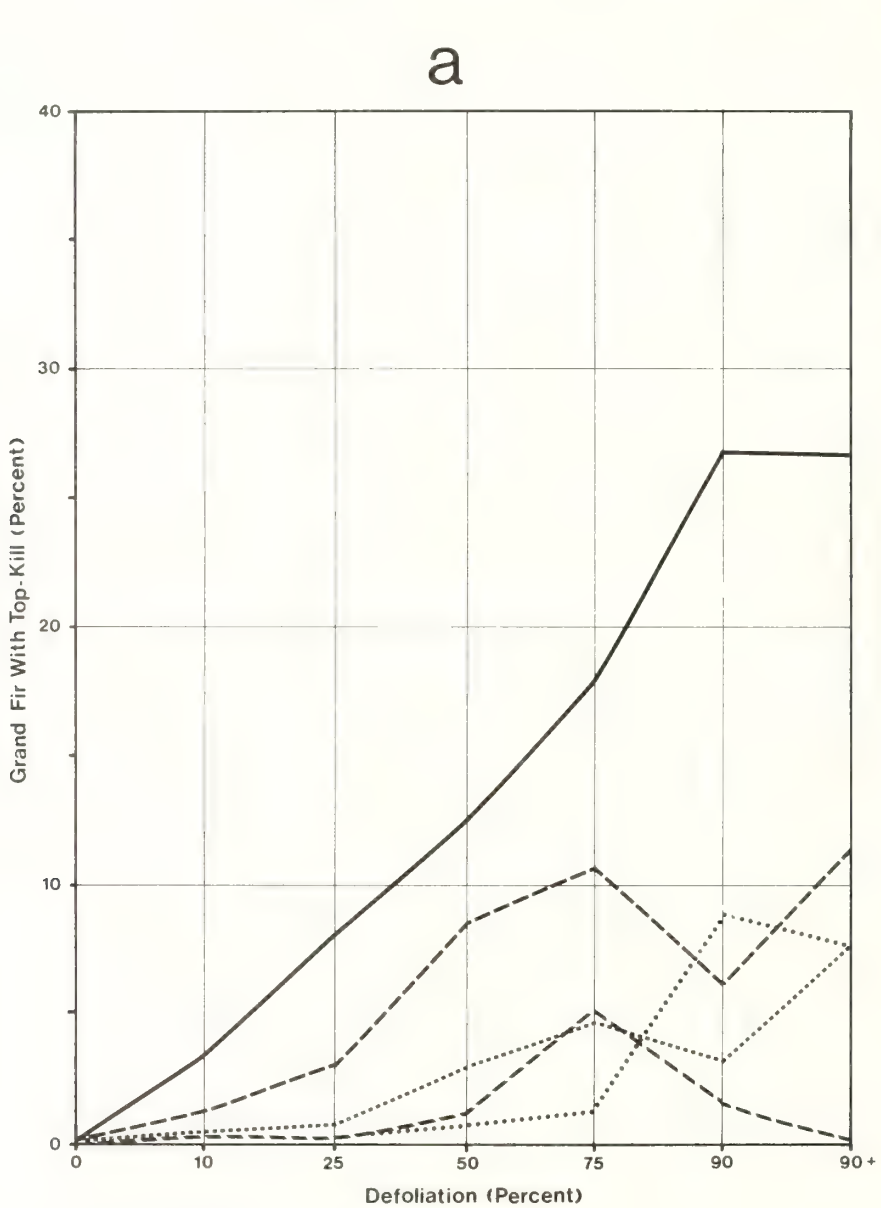


*Figure 13.--a, Percent of grand fir in various top-kill classes by percent defoliation.*

*Figure 13.--b, Percent of Douglas-fir in various top-kill classes by percent defoliation.*

10 percent of the crown top-killed were the next highest class, and most of this damage occurred in trees defoliated 25 to 75 percent. In grand fir, 4.8 percent of the top-kill occurred in this class and, in Douglas-fir, it was 12.7 percent. A consistent trend of top-kill incidence was found,

severity increased with severity of defoliation of grand fir, with a total of 8.4 percent of the trees suffering top-kill exclusive of leader-only damage. Leader mortality temporarily affects growth, but it rarely causes deformity in the tree crown. Within a year or two of the leader damage, a lateral is established as a new terminal; and detecting the damage later is almost impossible. Some deformity can occur when two laterals continue to maintain dominance in terminal growth, resulting in a fork-top tree.

In Douglas-fir, the trend was not as consistent except for the leader-only class. Top-kill peaked in the 75-percent defoliation category, and then dropped off in the 90- and 90+-percent categories with a total of 16.4 percent of the Douglas-fir suffering top-kill exclusive of leader-only damage.

Severe top-kill (greater than 25 percent of the crown) amounted to only 2 percent of the total for both tree species, and most of this damage occurred in trees defoliated 75 percent or more. Top-kill of this magnitude would usually be included in salvage logging programs.

*Related to d.b.h. class.*--Top-kill was also summarized in d.b.h. classes and the five top-kill classes (table 15, appendix). For grand fir, 17 percent of the trees larger than 12 inches d.b.h. suffered some top-kill exclusive of leader-only damage (fig. 14a). In Douglas-fir, 8.8 percent of trees 12- to 24-inch d.b.h. suffered 1 to 10 percent of their crown length top-killed, and 25 percent of the trees larger than 24-inch d.b.h. suffered some form of top-damage exclusive of leader-only (fig. 14b).

These figures are comparable to the 12 percent of merchantable white fir (larger than 12-inch d.b.h.) top-killed in heavily defoliated areas in California (Wickman 1963). In that study, no further breakdown was made of top-damage by defoliation categories or d.b.h. classes. After the Stowe Reservoir outbreak, however, we found 19-percent top-kill with a similar distribution by diameter class (Wickman 1978).[8/]

The long-term effects of top-kill damage are related to d.b.h. class. Trees 25-inch d.b.h. and larger with less than 25 percent of the crown killed are probably not a significant economic loss because the trees are growing slowly at that age and harvest is imminent. Trees 25-inch d.b.h. and larger with more than 25 percent of the crown killed amounted to 4.5 percent of the top-killed grand fir and 8.3 percent of the top-killed Douglas-fir in this d.b.h. class, and most of these trees will probably be salvage logged where accessible. The next smaller merchantable size class (12- to 24-inch d.b.h.) are intermediate in harvest priority, but crowns top-killed more than 25 percent should be salvaged with the larger trees.

Decay volumes increased with age and basal diameter of dead tops in a recent study of top-kill caused by tussock moth in the Blue Mountains.[9/] In

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[8/] Unpublished data on file at Forestry Sciences Laboratory, Corvallis, Oregon.

[9/] Aho, Paul E., Boyd E. Wickman, and Lee Roe. Incidence and rate of decay in host trees top-killed by Douglas-fir tussock moth in the Blue Mountains. In preparation for publication, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

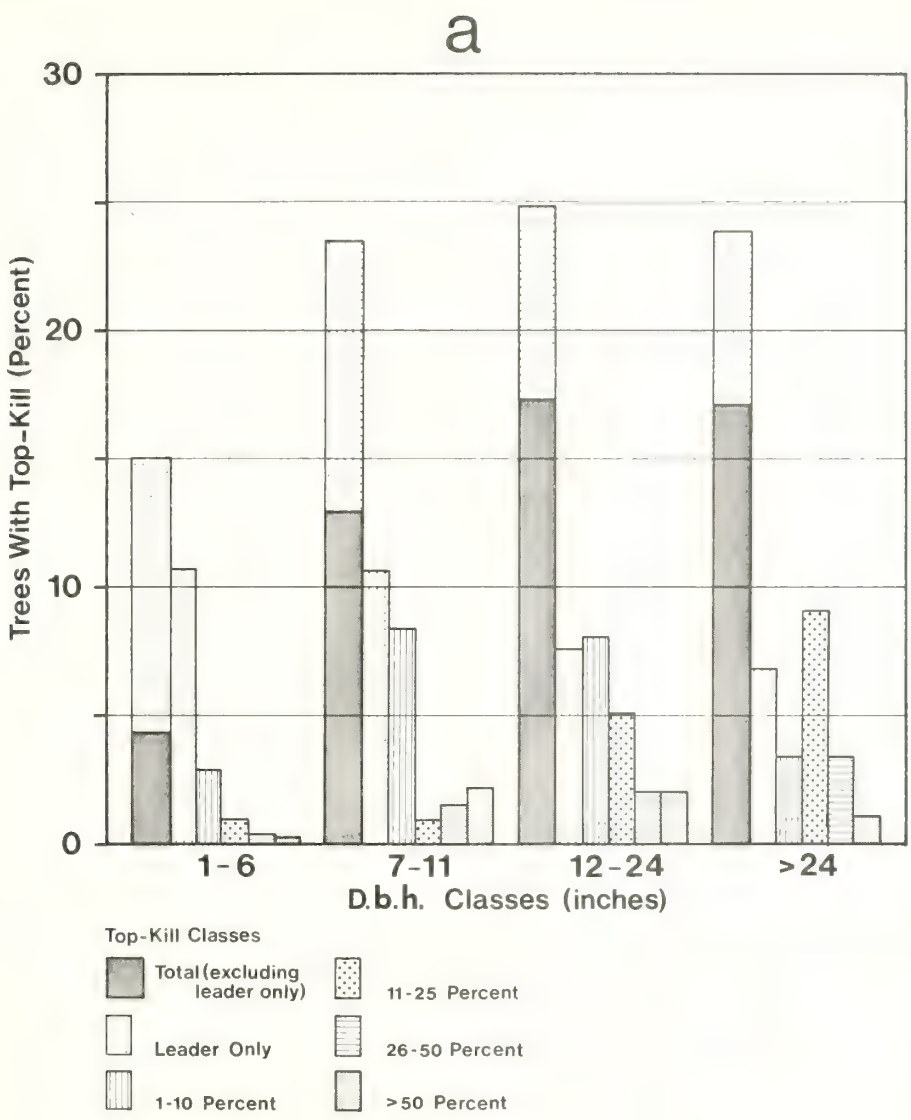


*Figure 14.--a, Percent of grand fir trees in various top-kill classes (percent of crown killed) by d.b.h. classes (based on living trees, 1976).*

stands of white fir on the east side of the Sierra Nevada fir stands, however, the threat of decay was not economically serious in merchantable trees 35 to 40 years after top-kill (Wickman and Scharpf 1972).

Top-kill in trees smaller than 12-inch d.b.h. is much more serious in terms of future growth and merchantability. In grand fir, 4.3 percent of the trees in the 1- to 6-inch d.b.h. class and 12.9 percent of the trees in the 7- to 11-inch d.b.h. class suffered top-kill, exclusive of leader-only damage. In Douglas-fir, the concentration of top-damage in these d.b.h. classes was much higher at 14.6 and 21.1 percent, respectively.

*Distribution in four defoliation classes.*--Top-kill was also summarized by the four de-

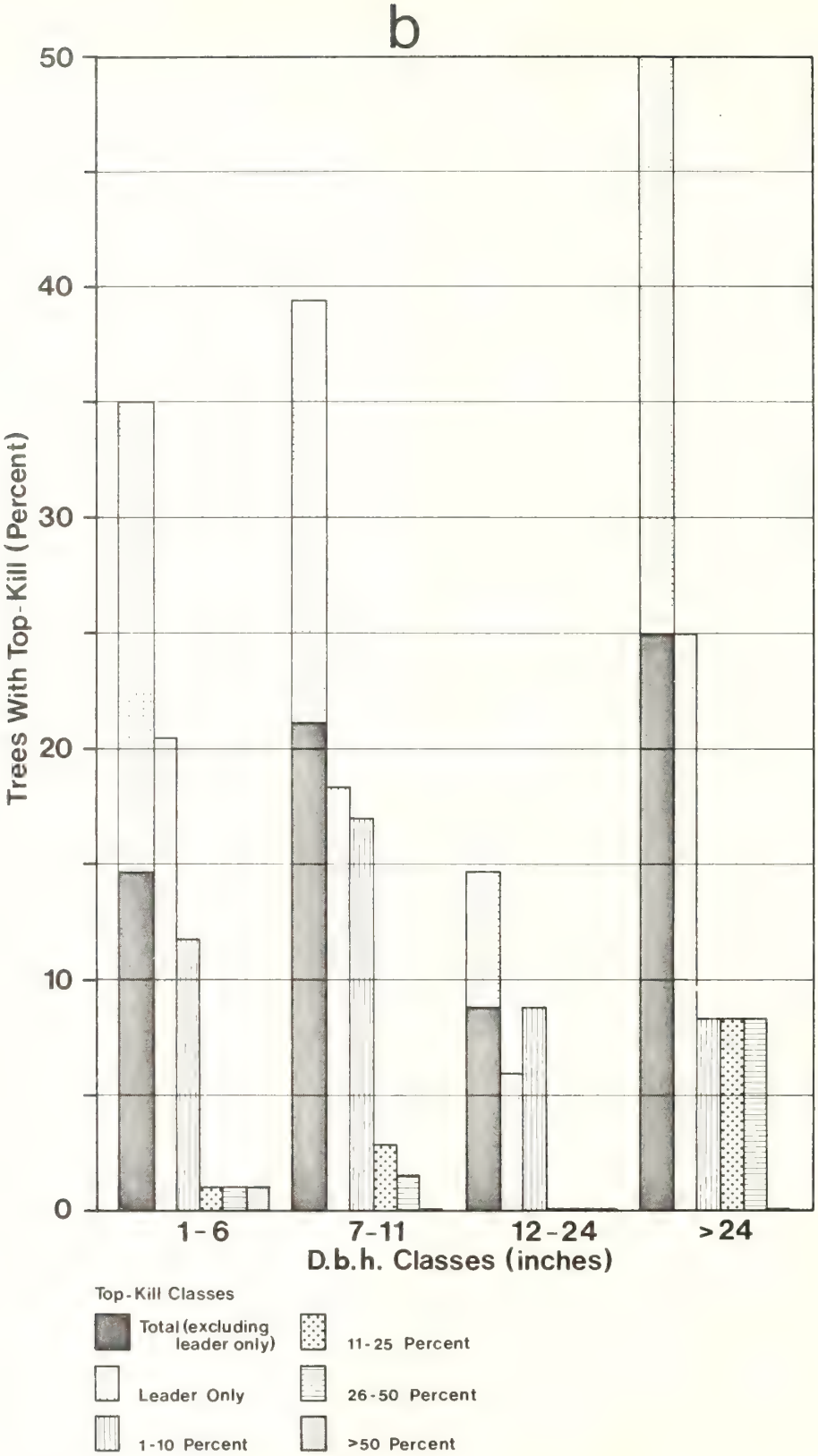


*Figure 14.--b, Percent of Douglas-fir trees in various top-kill classes (percent of crown killed) by d.b.h. classes (based on living trees, 1976).*

foliation classes of 1972. It was further stratified by the four mapped classes (table 16, appendix) and the four individual-plot defoliation classes (table 17, appendix) just as the tree mortality was organized earlier. These tables break down the percent top-kill in each of the top-kill classes by each of the broad defoliation classes. When top-kill is stratified by mapped defoliation class areas, most of the top-kill occurred in Douglas-fir, and the top damage was fairly evenly distributed through all four classes for both species. When stratified by the individual-plot defoliation class areas, Douglas-fir again suffers more than double the amount of top-kill of grand fir--but, most important, the top-kill is more realistically concentrated in the heavy class for grand fir and the heavy and moderate classes for Douglas-fir. Total top-kill, exclusive of leader-only damage for each of the tree species and the four mapped defoliation classes and four individual-plot classes is illustrated in figure 15.

The differences between the two methods of stratifying damage is not as pronounced in the relation of top-kill as they are for tree mortality. For both forms of damage, however, more tree damage occurs in the heavy class when stratified by individual-plot classes than by the mapped classes. The overall trend of top-kill in the four classes, by both methods of stratification, is similar to the trends of tree mortality presented earlier. The most striking relation in figure 15 is that Douglas-fir suffered more than double the amount of top-kill as grand fir.

One other interesting fact regarding top-kill emerged during this analysis of top-kill in the four defoliation classes. That was the level of top-kill before the outbreak, shown in table 8. Because this is not based on living trees in 1976, but rather on top-kill at the time of plot establishment, it gives some insight into "normal" or nonoutbreak-related top-kill in this section of the Blue Mountains. Top-kill before the outbreak for both grand fir and Douglas-fir was 8 and 6 percent, respectively.

When graphed (fig. 19, appendix) the low level of preoutbreak top-kill on heavy defoliation areas is evident. The reasons for this are not known. Perhaps it relates to population behavior of the tussock moth. The most dense populations may need full-crowned trees with a low level of chronic top-kill.

The Blue Mountains, or at least the outbreak areas, seem to suffer a chronic top-kill problem, related to a variety of biological and environmental causes. A windstorm in the winter of 1974, for instance, caused some severe top breakage on many of our plots. Other causes are bark beetles, mistletoe in Douglas-fir, porcupines, and snow damage.

*Grand fir and Douglas-fir top-kill compared.*--Figure 15 compares top-kill between grand fir and Douglas-fir for the four defoliation classes. Douglas-fir, suffering more than double the top-kill of grand fir--similar to the tree mortality relation--demonstrated more damage. This relation was investigated further by totaling the top-kill by species for each of the individual tree defoliation categories from table 14, appendix, and then graphing them separately (fig. 16). This graph shows that the trend for each species was similar, with the percent of Douglas-

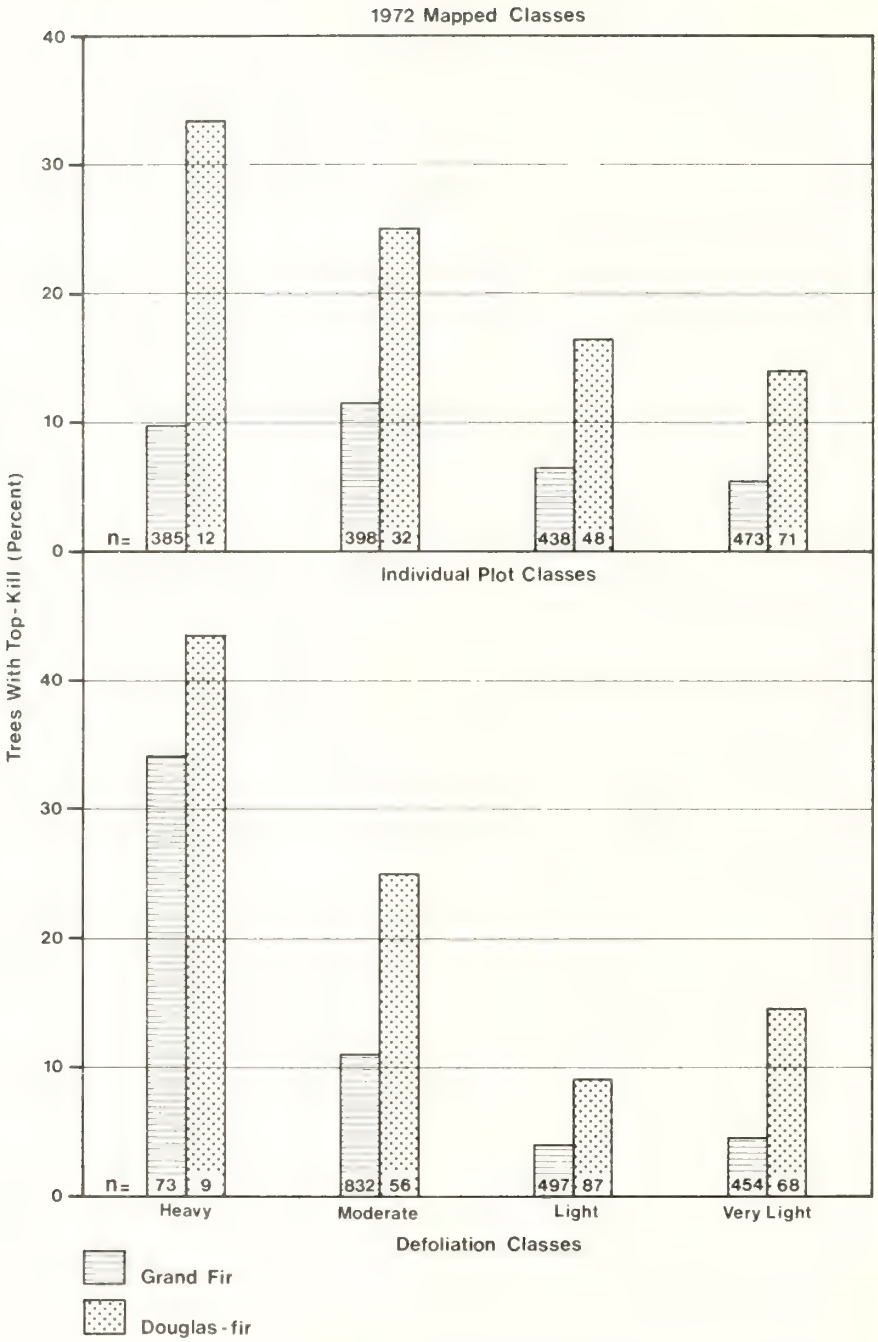


*Figure 15.--Percent of trees with top-kill each 1972 defoliation class, exclusive of leader-only damage (based on living trees, 1976).*

Table 8 --*Percent of trees with top-kill before Douglas-fir tussock moth defoliation, by defoliation classes*

| efoliation class | Mapped defoliation classes | | Individual-plot defoliation classes | |
|---|---|---|---|---|
| | Grand fir | Douglas-fir | Grand fir | Douglas-fir |
| eavy | 3.7 | 2.2 | 1.1 | 1.4 |
| oderate | 12.1 | 13.0 | 9.9 | 13.6 |
| ight | 8.7 | 11.9 | 6.6 | 5.0 |
| ery light | 8.7 | 6.5 | 9.3 | 6.9 |
| Total | 8.0 | 6.7 | 7.9 | 5.9 |

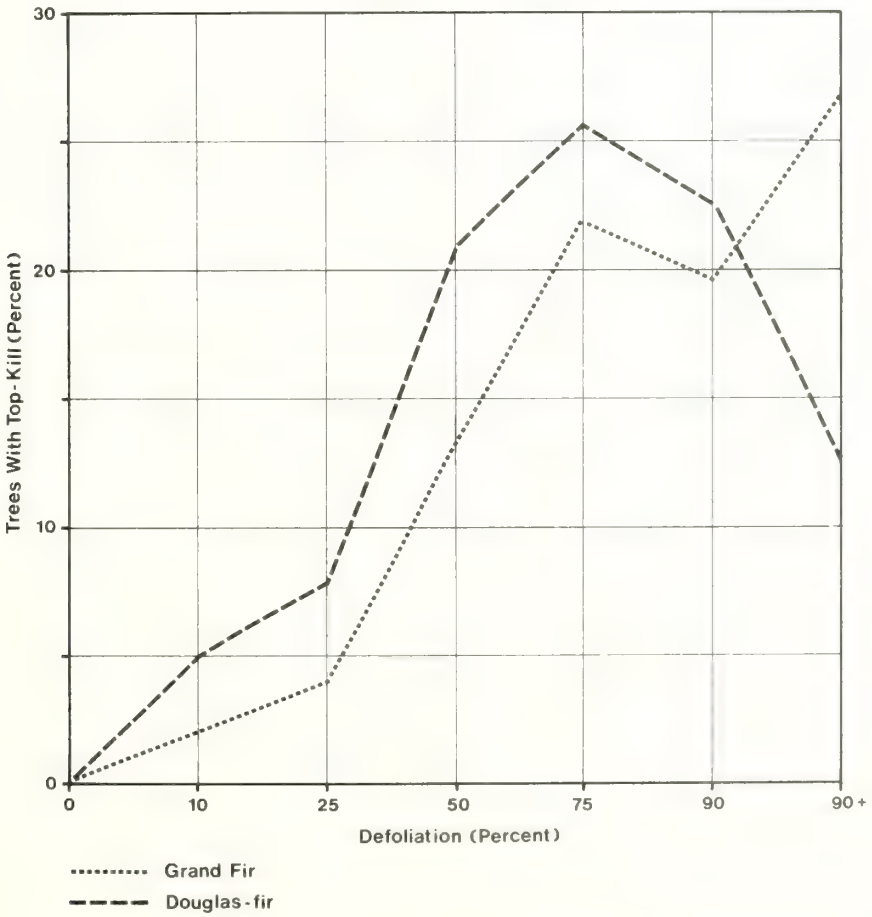


*Figure 16.--Percent top-kill by defoliation categories (excluding leader-only damage).*

fir top-kill higher than for grand fir up to the 90+-percent defoliation category when the trends drastically reversed. Almost 27 percent of the grand fir in this category suffered some top-kill (exclusive of leader-only), but Douglas-fir declined sharply to 12.5 percent of the survivors of this class with top-kill. This anomaly may not be significant because the data point consists of an eight-tree sample.

Next, the percent top-kill in each of the d.b.h. classes was summarized by species from table 15, appendix, and graphed in figure 17. And again, Douglas-fir suffered more top-kill in all except the 12- to 24-inch d.b.h. class. The trend here was drastically reversed with Douglas-fir suffering half as much top-kill as grand fir in this class (8.8 to 17.3 percent). The reason for this was unknown.

The pattern of Douglas-fir suffering more tree damage than grand fir in this outbreak remained consistent through the top-kill analysis as well as defoliation levels and tree mortality.

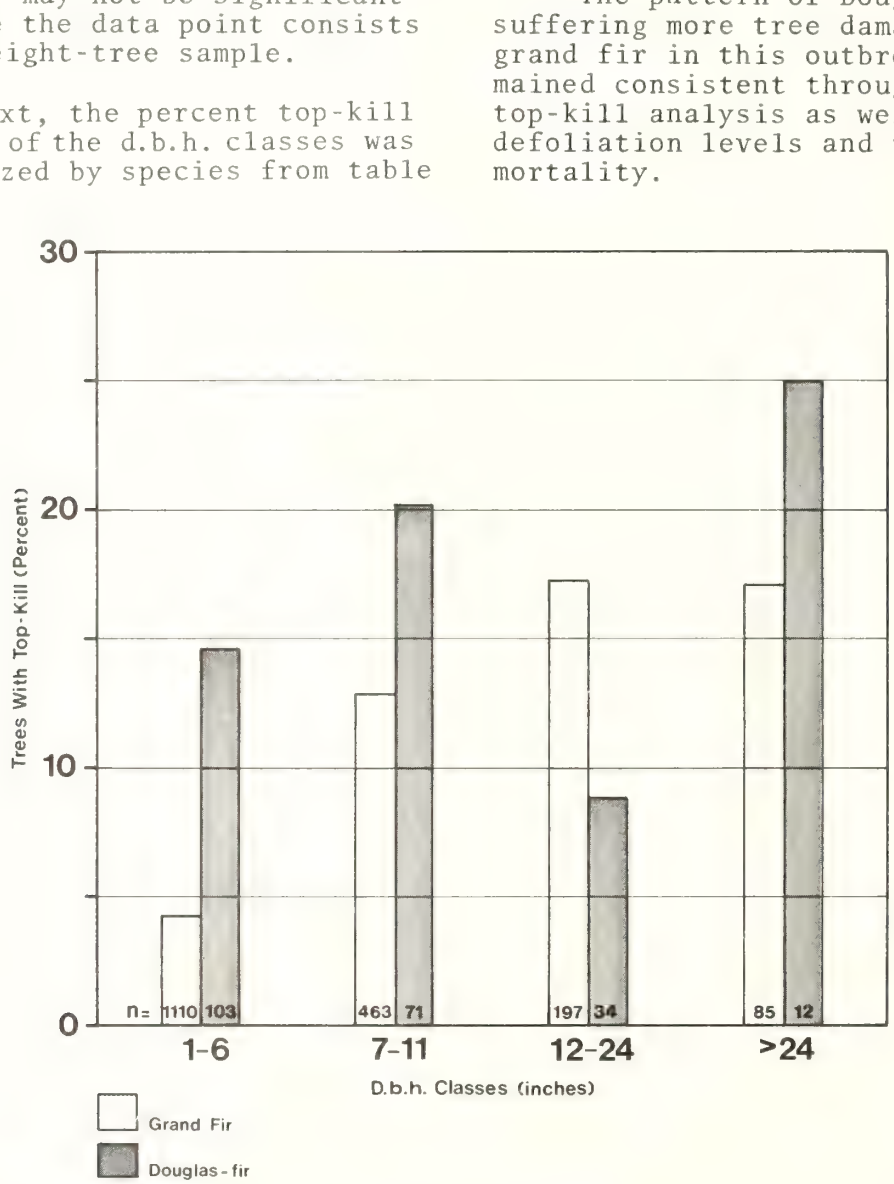


*Figure 17.--Percent top-killed trees by d.b.h. classes (excluding leader-only damage).*

*Related to tree mortality rom bark beetles.*--In past utbreaks, for several years ome top-killed white fir seemed o absorb repeated attacks by ark beetles near the top-killed ortion of the crown, sometimes esulting in progressive crown ie-back and tree mortality Wickman 1963). An analysis as made to see if some top- ill classes were more suscep- ible to mortality from bark eetles than others. Mortality as tallied by year and cause for ach species from 1974, when utbreak-caused top-kill could irst be determined, to 1976 for ach top-kill class (table 9).

A trend of increasing mor- ality from bark beetles with ncreased percent of crown top- illed is evident for Douglas-fir illed by Douglas-fir beetle. he trend is less evident for rand fir killed by fir engraver beetles, except in the 50-percent or greater top-killed class, where 47.2 percent of the trees were subsequently killed. The data base for the Douglas-fir is not large, but obviously both species with more than 50 percent of the crown top-killed have a high probability of being killed by bark beetles for at least several years after the outbreak subsides. This relation has also been used as a predictor for mortality from bark beetles in the Douglas-fir tussock moth outbreak model (see footnote 1). It should also be useful to the forest manager, when used in combination with percent of crown totally defoliated, for predicting tree mortality. Trees with 90 percent of the crown defoliated or 50 percent or more of the crown subsequently top-killed have a high probability of dying after a Douglas-fir tussock moth outbreak.

Table 9-- *Percent of each top-kill class that was killed by bark beetles for Douglas-fir and grand fir (trees killed by tussock moth or other causes were excluded)*

| Species | Percent of crown top-killed | | | | |
|---|---|---|---|---|---|
| | Leader only | 0-10 | 11-25 | 26-50 | >50 |
| Grand fir | 0.5 | 2.2 | 3.0 | 5.3 | 47.2 |
| Douglas-fir | 0.0 | 3.4 | 33.3 | 25.0 | 66.7 |

| Species | Total trees by top-kill classes (living trees and trees killed by bark beetle) | | | | |
|---|---|---|---|---|---|
| | Leader only | 0-10 | 11-25 | 26-50 | >50 |
| Grand fir | 190 | 91 | 33 | 19 | 36 |
| Douglas-fir | 39 | 29 | 6 | 4 | 3 |

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# Appendix

Table 10--*Comparison and t-test for significance between percent defoliation means of Douglas-fir (DF) and grand fir (GF) for each defoliation class in 1972 and 1973*

| Defoliation class | Year | Species | Mean | S.E. | T value | |
|---|---|---|---|---|---|---|
| Heavy | 1972 | DF | 92.38 | 2.40 | 1.17 | N.S. |
| | | GF | 88.73 | 1.93 | | |
| | 1973 | DF | 86.35 | 4.96 | 0.80 | N.S. |
| | | GF | 82.26 | 2.54 | | |
| Moderate | 1972 | DF | 39.02 | 3.64 | 0.31 | N.S. |
| | | GF | 38.03 | 1.31 | | |
| | 1973 | DF | 54.09 | 3.68 | 3.65 | * * |
| | | GF | 42.47 | 1.32 | | |
| Light | 1972 | DF | 10.82 | 0.52 | 1.58 | N.S. |
| | | GF | 12.52 | 0.71 | | |
| | 1973 | DF | 46.34 | 4.97 | 2.93 | * * |
| | | GF | 30.87 | 2.78 | | |
| Very light | 1972 | DF | 0.30 | 0.30 | 0.42 | N.S. |
| | | GF | 0.18 | 0.13 | | |
| | 1973 | DF | 57.25 | 5.62 | 3.09 | * * |
| | | GF | 36.67 | 3.86 | | |

N.S. = Not significant.

* * = Significant at .01 level.

Table 11--*Percent mortality and total number of Douglas-fir (DF) and grand fir (GF) by year of death and mapped defoliation class*

| Year | Defoliation class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Heavy | | Moderate | | Light | | Very light | |
| | DF | GF | DF | GF | DF | GF | DF | GF |
| | Percent stand (volume) | | | | | | | |
| 1972 | 3.0 | 20.4 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1973 | 3.7 | 5.9 | 1.1 | 1.1 | 0.6 | 0.0 | 0.3 | 0.0 |
| 1974 | 2.6 | 6.4 | 4.6 | 0.1 | 0.4 | 0.0 | 3.1 | 1.1 |
| 1975 | 0.8 | 2.5 | 2.7 | 5.5 | 0.1 | 0.0 | 0.3 | 0.4 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.7 | 0.0 | 3.1 |
| Totals | 10.1 | 35.2 | 8.4 | 7.0 | 1.5 | 0.7 | 3.7 | 4.6 |
| | 45.3 | | 15.4 | | 2.2 | | 8.3 | |
| | Percent stand (number) | | | | | | | |
| 1972 | 11.7 | 12.7 | 0.4 | 3.8 | 0.0 | 0.2 | 0.0 | 0.0 |
| 1973 | 3.0 | 4.1 | 1.4 | 1.8 | 0.2 | 0.8 | 2.1 | 3.2 |
| 1974 | 0.7 | 5.6 | 0.6 | 1.0 | 0.8 | 1.7 | 2.3 | 4.0 |
| 1975 | 0.3 | 0.5 | 0.8 | 0.8 | 0.2 | 0.8 | 0.3 | 0.5 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.4 | 0.0 | 0.2 |
| Totals | 15.7 | 22.9 | 3.2 | 7.4 | 1.4 | 3.9 | 4.7 | 7.9 |
| | 38.6 | | 10.6 | | 5.3 | | 12.6 | |

Total number of trees by defoliation class

| Species | Heavy | Moderate | Light | Very light | Total |
|---|---|---|---|---|---|
| Grand fir | 596 | 446 | 478 | 548 | 2,068 |
| Douglas-fir | 138 | 54 | 53 | 108 | 353 |
| Total | 734 | 500 | 531 | 656 | 2,421 |

Table 12--*Percent mortality and total number of Douglas-fir (DF) and grand fir (GF) by year of death and individual-plot defoliation class*

| Year | Defoliation class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Heavy | | Moderate | | Light | | Very light | |
| | DF | GF | DF | GF | DF | GF | DF | GF |
| | Percent stand (volume) | | | | | | | |
| 1972 | 4.6 | 30.7 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1973 | 16.6 | 11.1 | 0.1 | 0.1 | 0.7 | 0.0 | 0.3 | 0.0 |
| 1974 | 0.2 | 9.6 | 3.5 | 0.1 | 0.5 | 0.0 | 3.3 | 1.2 |
| 1975 | 1.2 | 10.5 | 1.6 | 1.6 | 0.2 | 0.0 | 0.3 | 0.4 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.8 | 0.0 | 3.2 |
| Totals | 22.6 | 61.9 | 5.2 | 2.0 | 1.9 | 0.8 | 3.9 | 4.8 |
| | 84.5 | | 7.2 | | 2.7 | | 8.7 | |
| | Percent stand (number) | | | | | | | |
| 1972 | 21.3 | 27.2 | 0.1 | 0.4 | 0.0 | 0.1 | 0.0 | 0.0 |
| 1973 | 6.8 | 6.9 | 0.4 | 1.3 | 0.9 | 0.9 | 1.8 | 3.2 |
| 1974 | 0.4 | 8.4 | 0.6 | 1.2 | 0.9 | 2.5 | 2.3 | 3.1 |
| 1975 | 0.5 | 0.5 | 0.4 | 0.8 | 0.1 | 0.5 | 0.3 | 0.2 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.3 | 0.0 | 0.2 |
| Totals | 29.0 | 43.0 | 1.5 | 3.7 | 2.0 | 4.3 | 4.4 | 6.7 |
| | 72.0 | | 5.2 | | 6.3 | | 11.1 | |

Total number of trees by defoliation class

| Species | Heavy | Moderate | Light | Very light | Total |
|---|---|---|---|---|---|
| Grand fir | 268 | 911 | 548 | 518 | 2,245 |
| Douglas-fir | 140 | 81 | 120 | 101 | 442 |
| Total | 408 | 992 | 668 | 619 | 2,687 |

Table 13-- *Chi-square test for difference in probability of mortality between Douglas-fir and grand fir and in different individual tree defoliation categories*

| Defoliation categories | Number of trees | | | | |
|---|---|---|---|---|---|
| | Condition | Douglas-fir | Grand fir | $\chi^2$ (1) | Significance |
| 0-75 | alive | 206 | 1,801 | 0.52 | N.S. |
| | dead | 2 | 10 | | |
| 90 | alive | 46 | 160 | 0.62 | N.S. |
| | dead | 12 | 31 | | |
| 99 | alive | 14 | 31 | 0.04 | N.S. |
| | dead | 12 | 29 | | |
| 100 | alive | 14 | 11 | 1.27 | N.S. |
| | dead | 133 | 167 | | |

Table 14 --*Percent of trees in various top-kill classes by percent defoliation categories (based on living trees, 1976)*

| Percent defoliation category | No. | Percent of crown top-killed | | | | | | Total minus leader |
|---|---|---|---|---|---|---|---|---|
| | | Leader only | 1-10 | 11-25 | 26-50 | >50 | Total | |
| | | | | GRAND FIR | | | | |
| 10 | 537 | 3.4 | 1.3 | 0.4 | 0.4 | 0.0 | 5.4 | 2.0 |
| 25 | 571 | 8.2 | 3.0 | 0.7 | 0.2 | 0.0 | 12.1 | 3.9 |
| 50 | 448 | 12.5 | 8.5 | 2.9 | 1.1 | 0.7 | 25.7 | 13.2 |
| 75 | 150 | 18.0 | 10.7 | 4.7 | 5.3 | 1.3 | 40.0 | 22.0 |
| 90 | 126 | 27.0 | 6.3 | 3.2 | 1.6 | 8.7 | 46.8 | 19.8 |
| 90+ | 26 | 26.9 | 11.5 | 7.7 | 0.0 | 7.7 | 53.8 | 26.9 |
| Total | 1,858 | 10.2 | 4.8 | 1.7 | 1.0 | 1.0 | 18.6 | 8.4 |
| | | | | DOUGLAS-FIR | | | | |
| 10 | 40 | 7.5 | 5.0 | 0.0 | 0.0 | 0.0 | 12.5 | 5.0 |
| 25 | 39 | 15.4 | 7.7 | 0.0 | 0.0 | 0.0 | 23.1 | 7.7 |
| 50 | 67 | 16.4 | 19.4 | 0.0 | 1.5 | 0.0 | 37.3 | 20.9 |
| 75 | 35 | 25.7 | 17.1 | 5.7 | 2.9 | 0.0 | 51.4 | 25.7 |
| 90 | 31 | 22.6 | 9.7 | 6.5 | 3.2 | 3.2 | 45.2 | 22.6 |
| 90+ | 8 | 37.5 | 12.5 | 0.0 | 0.0 | 0.0 | 50.0 | 12.5 |
| Total | 220 | 17.7 | 12.7 | 1.8 | 1.4 | 0.5 | 34.1 | 16.4 |

Table 15--*Percent of trees in various top-kill classes by d.b.h. class (based on living trees, 1976)*

| D.b.h. class (inches) | No. | Percent of crown top-killed | | | | | | Total minus leader |
|---|---|---|---|---|---|---|---|---|
| | | Leader only | 1-10 | 11-25 | 26-50 | >50 | Total | |
| | | | | GRAND FIR | | | | |
| 1 - 6 | 1,110 | 10.7 | 2.8 | 0.9 | 0.4 | 0.3 | 15.0 | 4.3 |
| 7 - 11 | 463 | 10.6 | 8.4 | 0.9 | 1.5 | 2.2 | 23.5 | 12.9 |
| 12 - 24 | 197 | 7.6 | 8.1 | 5.1 | 2.0 | 2.0 | 24.9 | 17.3 |
| >24 | 88 | 6.8 | 3.4 | 9.1 | 3.4 | 1.1 | 23.9 | 17.1 |
| Total | 1,858 | 10.2 | 4.8 | 1.7 | 1.0 | 1.0 | 18.6 | 8.4 |
| | | | | DOUGLAS-FIR | | | | |
| 1 - 6 | 103 | 20.4 | 11.7 | 1.0 | 1.0 | 1.0 | 35.0 | 14.6 |
| 7 - 11 | 71 | 18.3 | 16.9 | 2.8 | 1.4 | 0.0 | 39.4 | 21.1 |
| 12 - 24 | 34 | 5.9 | 8.8 | 0.0 | 0.0 | 0.0 | 14.7 | 8.8 |
| >24 | 12 | 25.0 | 8.3 | 8.3 | 8.3 | 0.0 | 50.0 | 25.0 |
| Total | 220 | 17.7 | 12.7 | 1.8 | 1.4 | 0.5 | 34.1 | 16.4 |

Table 16--*Percent of trees in various top-kill classes stratified by 1972 mapped defoliation classes (based on living trees, 1976)*

| Defoliation class | No. | Percent of crown top-killed | | | | | | Number of trees with top-kill |
|---|---|---|---|---|---|---|---|---|
| | | Leader only | 1-10 | 11-25 | 26-50 | >50 | Total | |
| | | | | GRAND FIR | | | | |
| Heavy | 385 | 15.1 | 5.2 | 1.6 | 1.6 | 1.6 | 24.9 | 96 |
| Moderate | 398 | 9.5 | 5.0 | 3.3 | 1.3 | 2.0 | 21.1 | 84 |
| Light | 438 | 3.9 | 4.6 | 1.1 | 0.7 | 0.2 | 10.5 | 46 |
| Very light | 473 | 9.9 | 3.6 | 1.5 | 0.4 | 0.2 | 15.6 | 74 |
| Total | 1,694 | 9.4 | 4.5 | 1.8 | 0.9 | 0.9 | 17.7 | 300 |
| | | | | DOUGLAS-FIR | | | | |
| Heavy | 12 | 25.0 | 8.3 | 16.7 | 8.3 | 0.0 | 58.3 | 7 |
| Moderate | 32 | 18.8 | 15.6 | 3.1 | 6.3 | 0.0 | 43.8 | 14 |
| Light | 48 | 8.3 | 14.6 | 0.0 | 0.0 | 2.1 | 25.0 | 12 |
| Very light | 71 | 21.1 | 12.7 | 1.4 | 0.0 | 0.0 | 35.2 | 25 |
| Total | 163 | 17.2 | 13.5 | 2.5 | 1.8 | 0.6 | 35.6 | 58 |

Table 17--*Percent of trees in various top-kill classes stratified by 1972 individual-plot defoliation classes (based on living trees, 1976)*

| Defoliation class | No. | Percent of crown top-killed | | | | | | Number of trees with top-kill |
|---|---|---|---|---|---|---|---|---|
| | | Leader only | 1-10 | 11-25 | 26-50 | >50 | Total | |
| | | | | GRAND FIR | | | | |
| Heavy | 73 | 34.2 | 13.7 | 4.1 | 6.8 | 9.6 | 68.5 | 50 |
| Moderate | 832 | 10.1 | 6.1 | 2.5 | 1.2 | 1.2 | 21.2 | 176 |
| Light | 497 | 7.4 | 3.0 | 0.4 | 0.2 | 0.2 | 11.3 | 56 |
| Very light | 454 | 9.5 | 2.9 | 1.2 | 0.4 | 0.0 | 14.1 | 64 |
| Total | 1,856 | 10.2 | 4.8 | 1.7 | 1.0 | 1.0 | 18.6 | 346 |
| | | | | DOUGLAS-FIR | | | | |
| Heavy | 9 | 44.4 | 22.2 | 22.2 | 0.0 | 0.0 | 88.9 | 8 |
| Moderate | 56 | 16.1 | 17.9 | 1.8 | 5.4 | 0.0 | 41.1 | 23 |
| Light | 87 | 14.9 | 8.0 | 0.0 | 1.1 | 1.1 | 24.1 | 21 |
| Very light | 68 | 19.1 | 13.2 | 1.5 | 0.0 | 0.0 | 33.8 | 23 |
| Total | 220 | 17.7 | 12.7 | 1.8 | 1.4 | 0.5 | 34.1 | 75 |

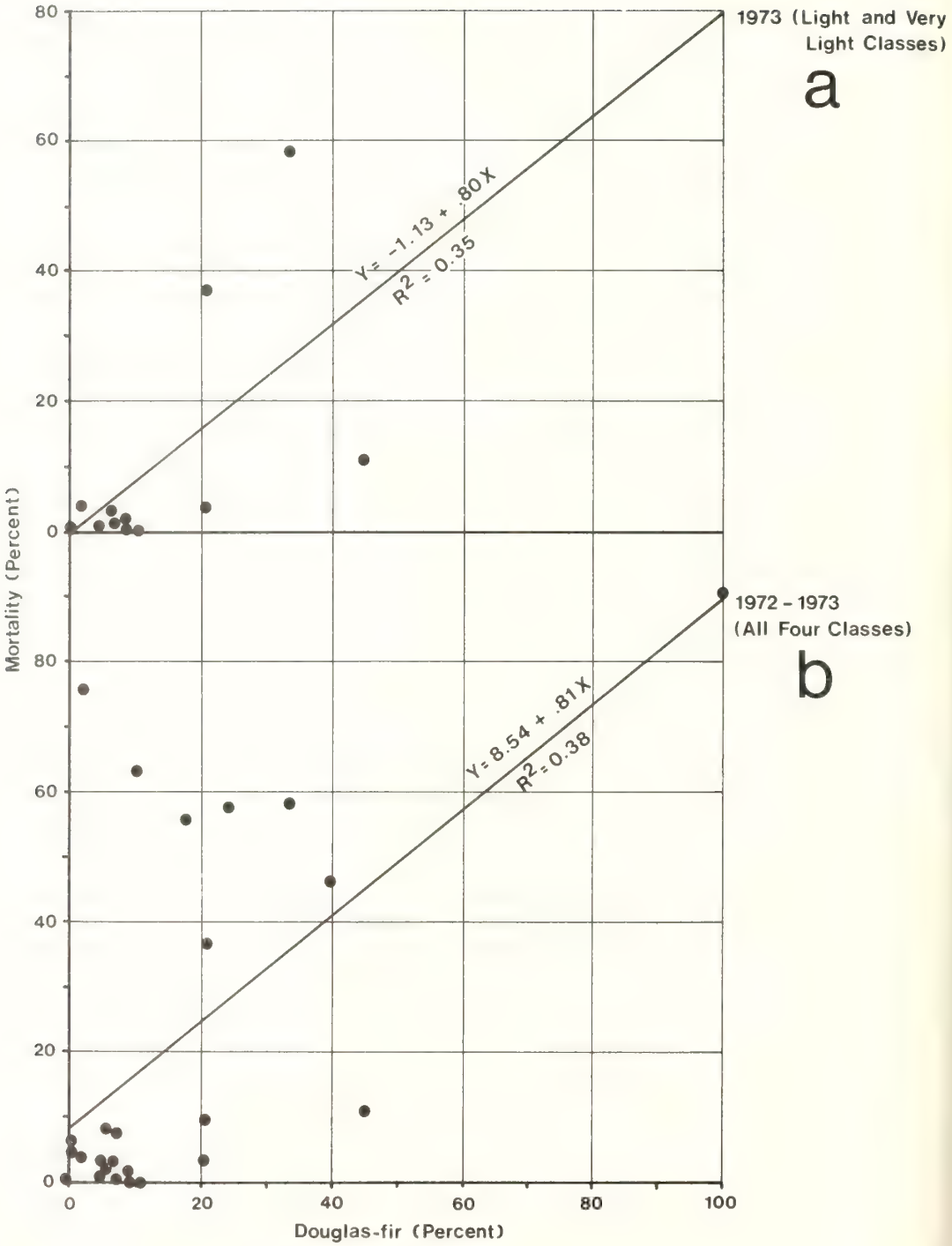


*Figure 18.--The effect of percent Douglas-fir on total mortality of grand fir and Douglas-fir in light and very light classes from 1973 defoliation (a) and from 1972-1973 defoliation of all classes (b).*

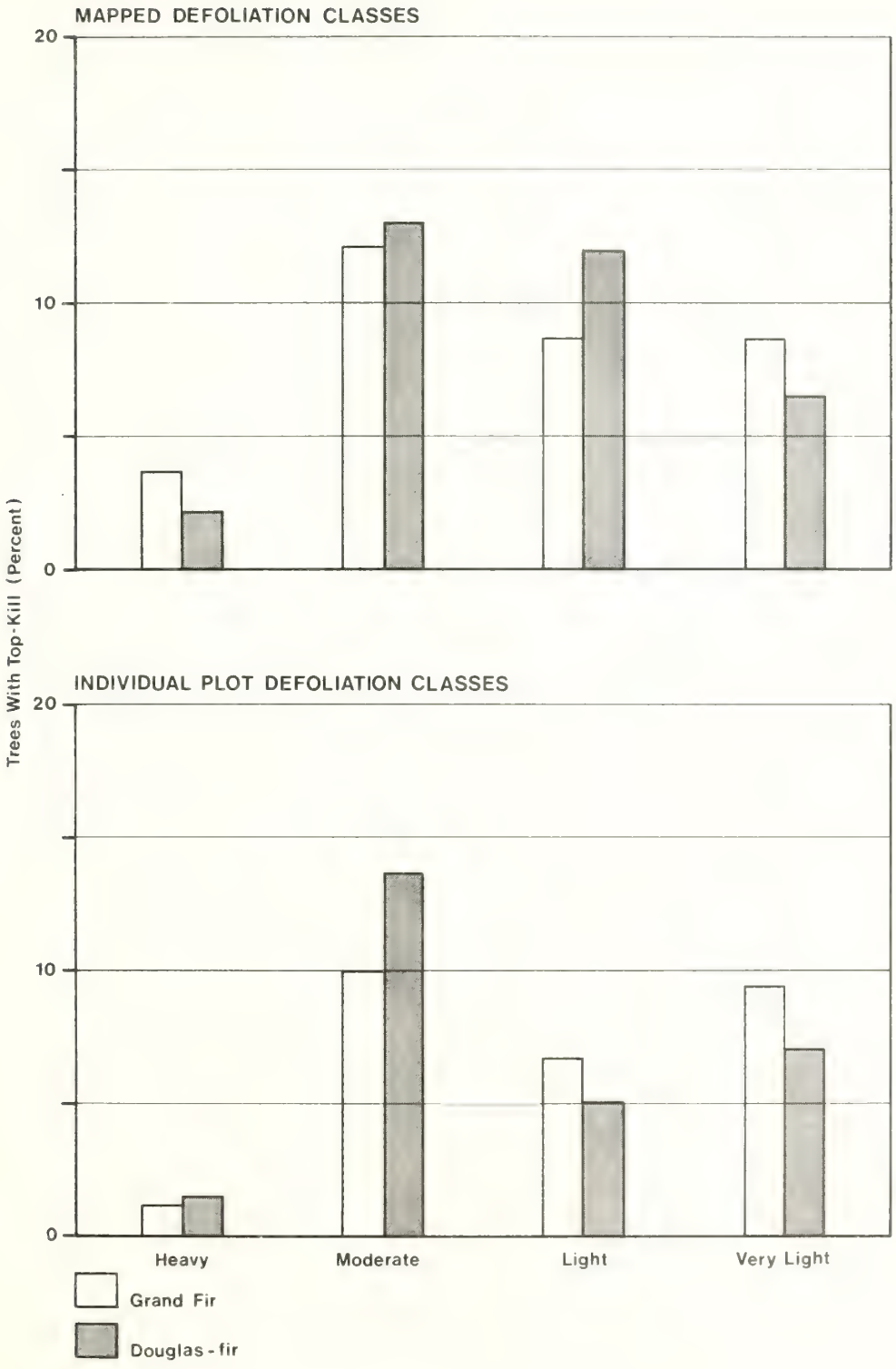


*Figure 19.--Percent of trees with top-kill before tussock moth defoliation.*



GPO 986-072

Wickman, Boyd E.
1978. Tree mortality and top-kill related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA For. Serv. Res. Pap. PNW-233, 47 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Tree damage was studied from 1972 to 1976 following a severe DFTM outbreak. Tree mortality was strongly related to percent defoliation with most occurring in trees defoliated 90 percent or more. Top-kill was also more severe in heavily defoliated trees.

KEYWORDS: Insect damage (-forest, defoliation damage, Douglas-fir tussock moth, *Orgyia pseudotsugata*, Douglas-fir, *Pseudotsuga menziesii*, grand fir, *Abies grandis*, Oregon (Blue Mountains), Washington (Blue Mountains).

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USDA FOREST SERVICE RESEARCH PAPER PNW-234
1978

# Changes in the Thermal Regime After Prescribed Burning and Select Tree Removal (Grass Camp, 1975)

W. B. Fowler
J. D. Helvey

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE
PORTLAND, OREGON

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# CHANGES IN THE THERMAL REGIME AFTER PRESCRIBED BURNING AND SELECT TREE REMOVAL (GRASS CAMP, 1975)

*Reference Abstract*

Fowler, W. B., and J. D. Helvey.
1978. Changes in the thermal regime after prescribed burning and select tree removal (Grass Camp, 1975). USDA For. Serv. Res. Pap. PNW-234, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Thermal regimes at several locations are examined following prescribed burn or mechanical removal of shading vegetation. While the forested control location indicated a trend in 1976 toward cooler and less variable air and soil temperatures, treated locations responded vigorously to changing site exposure. Moderate increases in air temperature maxima at sensor height of 0.5 m were noted at treated locations while soil temperature maxima at 0.01 m increased by 8° C on the grass slope and by 26° C in the burned snag patch. Double mass plots of accumulated degree hours illustrate the changing relationship between sites and indicate future trends as sites become revegetated.

KEYWORDS: Temperature (soil), soil temperature, air temperature (-site, fire use, fire effects, prescribed burning, vegetal cover -) fire control.

*RESEARCH SUMMARY*

*Research Paper PNW-234*

*1978*

This Research Paper presents data on changes in air and soil temperature following prescribed fire in two plant communities at 1730 meters near Wenatchee, Washington. These results are intended for use by plant ecologists, biologists, and others who are interested in microclimatic changes following fire at this high elevation site.

## Introduction

Prescribed fire offers promise as a management tool on east Cascade forest and range sites. Applications vary in size from treatment of individual plants (eradication of sagebrush or other brush species on rangelands, Hallman 1972) to the multiacre stand manipulation as in this example. The prescribed fire at Grass Camp, Wenatchee National Forest, eastern Washington, on September 30, 1976, was an operational test of prescribed fire to improve wildlife habitat (primarily for elk) and to control the encroachment of brush and tree species into a nearby high elevation (1 730 m) meadow. Three areas were designated for treatment: a grassy slope with invading lodgepole pine, a felled area with a high concentration of new slash, and an older snag thicket with a large accumulation of dead standing and windthrown material. Our measurements concentrated on the grassy slope and the snag thicket.

Burning of the grassy slope was not accomplished as originally planned. A hasty decision was made to increase site exposure by felling the small lodgepole pine shading this site, thus crudely simulating what fire and later windthrow might have accomplished, i.e., complete overstory removal.

A pretreatment aerial photo (fig. 1) indicates general site conditions: the inset map shows geographic location. A posttreatment photo (fig. 2) taken in 1976 shows extent of burn in the snag thicket. Indicated also on these photos are the instrumented locations (control, grass, and snag).

Stand conditions in the snag thicket are illustrated in figure 3. Accumulation of windthrown trees, standing snags to 20 m, and reproduction of all ages made access difficult. Figure 4 (foreground) shows the sparse cover on the grassy slope with isolated patches of young lodgepole pine. The control stand, lodgepole pine to 20 m tall, had complete canopy closure with only isolated grass and low shrub ground cover. Soils at all locations were derived from underlying basalt.

State college, university, and Pacific Northwest Forest and Range Experiment Station personnel are examining effects of this prescribed burn on local animal and plant communities. Plant and animal responses are intimately related to changes in the thermal regime; thus, results reported here may assist other workers in their evaluations. Direct measurement of the thermal regime, especially within the zone nearest the forest floor, is absent in other contemporary studies on this site.

Short- and longterm effects on the thermal regime after fire are of recognized importance in re-establishment and successional trends of the residual or new plant community. After the 1970 wildfire on the Entiat Experimental Forest, we found no significant changes in the July-August air temperature regime at weather shelter height. Measurements at this standard height, however, normally minimize the local microsite variability experienced nearer the soil surface. Postfire measurements on the soil surface showed highly variable maximum temperatures; temperatures strongly influenced by soil surface condition, type, and quantity of vegetation (Helvey et al. 1976). Air temperature at 0.5 m related well to phenologic development of a selected forb and shrub[1/] found in this elevational zone.[2/] Sampling

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[1/] *Apocynum androsaemifolium* L. and *Spiraea betulifolia* Pall.

[2/] Unpublished information on file at the Forest Hydrology Laboratory, Wenatchee, Washington.

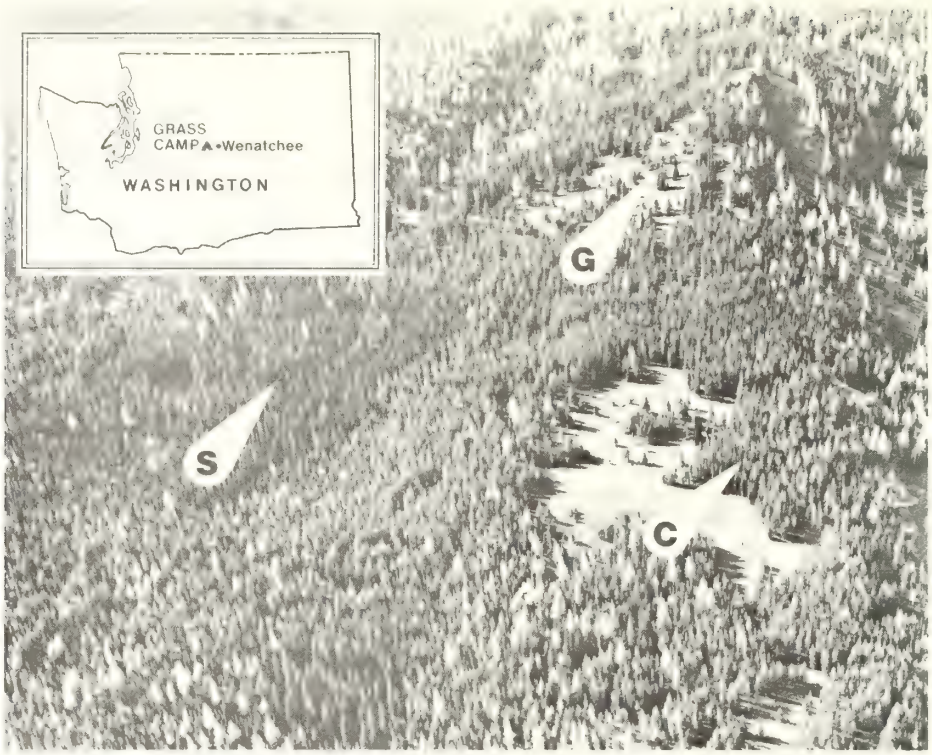


*Figure 1.--Pre-treatment view (towards southwest) of prescribed burn area. Instrumented sites, control (C), grass slope (G), and snag patch (S) are identified. Inset map shows location within Washington State.*

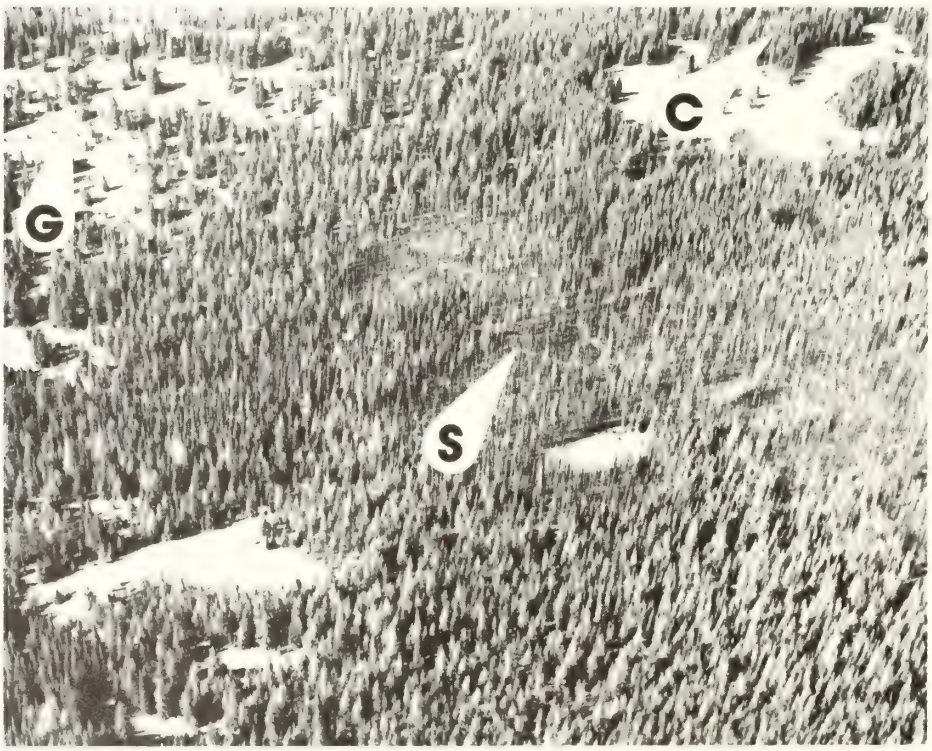


*Figure 2.--View towards northwest after prescribed burn of snag patch. Instrumented sites are indicated.*

*Figure 3.--Layered vegetation with standing and windthrown snags typified fuel conditions in snag thicket. Metal stand for temperature sensors may be visible near kneeling researcher.*

*Figure 4.--Encroaching lodgepole pine on grassy slope in foreground. Snag thicket burning in background.*

at the 0.5-m height and at the soil surface was therefore selected for the Grass Camp study. We felt that this height would be more revealing of local microsite temperature differences than standard weather shelter height and that it was within the microclimatic zone for re-establishing species.

With vegetation control one of the primary objectives of this burn, it was desirable to observe temperatures during the burn for subsequent explanation of observed plant response. Lethal temperature for protoplasm is about 50-60° C (120-140° F) for most plant tissue (Davis 1959, Meyer and Anderson 1952). Shielding of critical cambial tissue by thicker bark allows some plants to withstand much higher local temperatures. A fire of moderate intensity should kill the thin-barked species (spruce, fir, and lodgepole pine) found at this elevation.

Literature on air temperature distribution during prescribed burns in the east Cascades is limited. Temperatures are in response to fuels, moisture content, and local controls on combustion rates. Davis (1959) suggests temperatures of 1800° F (982° C) for low moisture fuels, 1600-1700° F (871-926° C) for fuels with high moisture contents of 40 percent or more, and that soil surface temperatures of 400° F (204° C) to 900° F (482° C) are common.

## Materials and Methods

Two types of maximum temperature sensors (metals and temperature-sensitive wax compounds) were installed in the snag thicket on the day of the fire (September 30, 1975). Melting point for maximum temperature sensors ranged from 183° C to 1 085° C (361° F to 1985° F). Metals: copper, aluminum, lead, and a lead-tin mixture had melting points of 1 085, 660, 327, and 183° C, respectively. Thermoplastics with melting points of 815, 732, 593, 537, 482, 426, 371, and 260° C supplemented the metals for 11 fixed points of maximum temperature measurement. Sampling heights varied and were up to 7 m above the forest floor. Nine sample points were located in a random pattern in the snag thicket. All locations were within 20 m of the recording site in an approximately circular pattern. A 10th location was in the adjoining lodgepole pine stand.

Recording integrating soil and air thermometers, operating on a 3-hour print cycle, were installed at a control location, snag thicket, and on the grassy slope. These recording devices were operated through the latter part of July until mid-October or early November 1975, and from June through September or October 1976. Instrument location on the grassy slope was on the shaded uphill edge of a sparse group of small lodgepole pine trees (3 m in overall diameter; trees to 3 m tall).

The recording thermometer produced a degree-hour summary above a reference temperature of -10° C[3/] or by conversion, calculated the average temperature for each 3-hour period. Sample heights were 0.5 m for air temperature and 0.01 m for soil temperature; accuracy and resolution of the measurement is ± 1 count per 3-hour period or ± 0.2° C.

## Results

### *AIR TEMPERATURE DURING BURNING*

A pictorial summary of maximum air temperatures at the selected heights and from the cable-supported sensors is shown in figure 5. For

[3/] A reference temperature of -10° C allowed the thermometer to register temperature excursions below freezing.

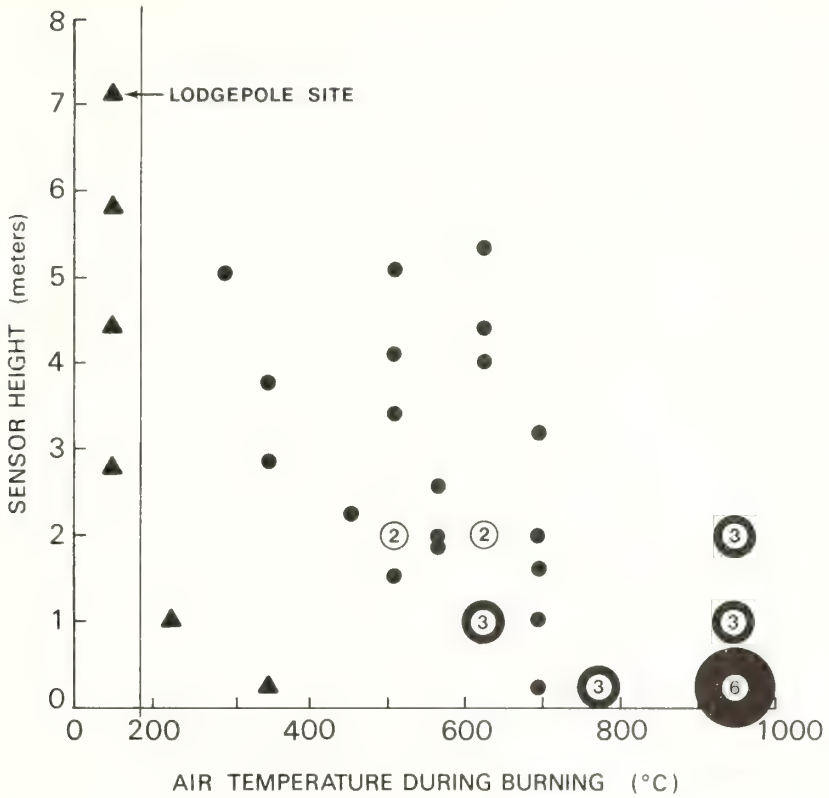


*Figure 5.--Temperature-height distribution during burning of snag thicket (spruce-fir) and lodgepole pine stand. Duplicate measurements shown by number and diameter of symbol.*

locations within the snag thicket, the range of temperature at each height and frequency of occurrence is shown plus the temperature profile for the single lodgepole pine location. Each measurement (height-temperature) is represented by a point in the figure. A variation in height of cable-supported sensors is noticeable. At locations where support for the cable was lost during the fire, measurements are shown at heights measured after the fire. Separate profiles for each location within the snag thicket are not shown due to overlapping of data points. Measurements were not available at six points due to loss of temperature sensors from falling debris or unknown causes.

All temperatures were within the measurement range of the sensors except for the four measurements less than 183° C (361° F) in the lodgepole pine stand. Resolution suffered in the grouping of data in the 815-1 085°C (1500-1985° F) range between the two highest responding sensors at the three lower levels of measurement. Each plotted point represents the midpoint of a temperature range (e.g. 221° C for the 183° C to 260° C range, at 950° C for the 815° C to 1 085° C range, etc).

## *AIR AND SOIL TEMPERATURE*

In contrast to the short-term temperature history during the fire (fig. 5), air and soil temperatures at the three locations over the 2 years present a variable, interrelated picture. Averaging of the data over

too long a time period reduces the resolution, damps out or at times even obscures the response. Analysis of the data, based on a minimum of 12-hour day versus night,[4/] is desirable to isolate these different energy input periods. To understand the differences between several sites during the 12-hour period, a brief analysis of three hourly periods for the snag soil and control soil is shown.

Simple graphical analysis for the various combinations of control versus treated sites indicated that the treatments affected the thermal regime at these sites. Figure 6 illustrates the response at the grass site for daytime air temperatures compared to the control location.

Daytime temperatures are obviously higher in 1976 than in 1975 for similar control site temperatures. Because of the discontinuous nature of the temperature data caused by the limited temperature excursion after treatment in 1975, the relationship between posttreatment 1975 data to the prior treatment 1975 or 1976 period is undefinable. This treatment of the data also suppresses any temporal or changing relationship within the separate data groups.

We have chosen two alternate procedures (Chow 1964) to examine the changing temperature relationship between the control versus treated sites: the double mass plot of accumulated degree hours and a frequency analysis of observed temperatures.

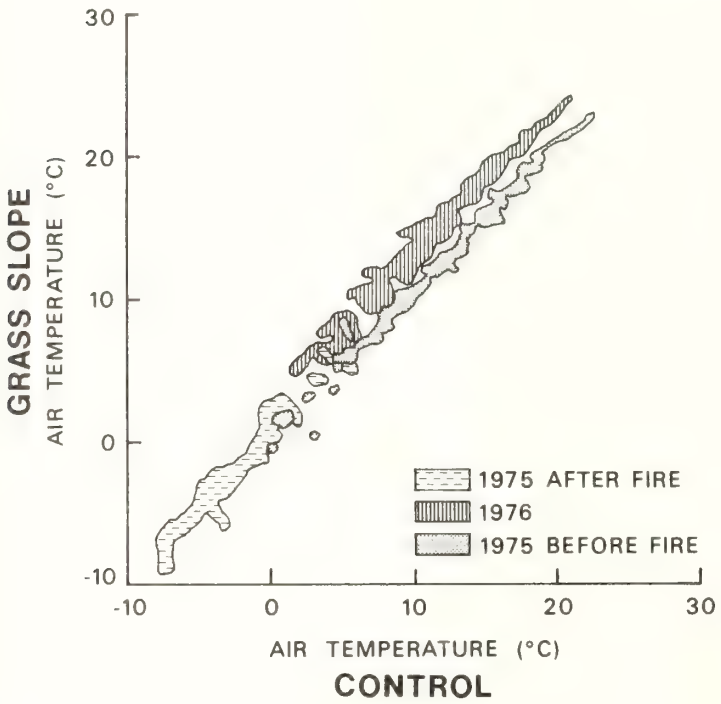


*Figure 6.--Relationship between daytime air temperature at control and grass sites for 1975 and 1976.*

Accumulated degree-hour summaries for the control versus snag patch and grassy slope based on a 3-hour printout are plotted in figures 7, 8, 9, and 10. Except for the expanded section (daily, i.e. 12-hour accumulations)

[4/] Daytime = between 0600-1800 hours. Nighttime = between 1800-0600 hours.

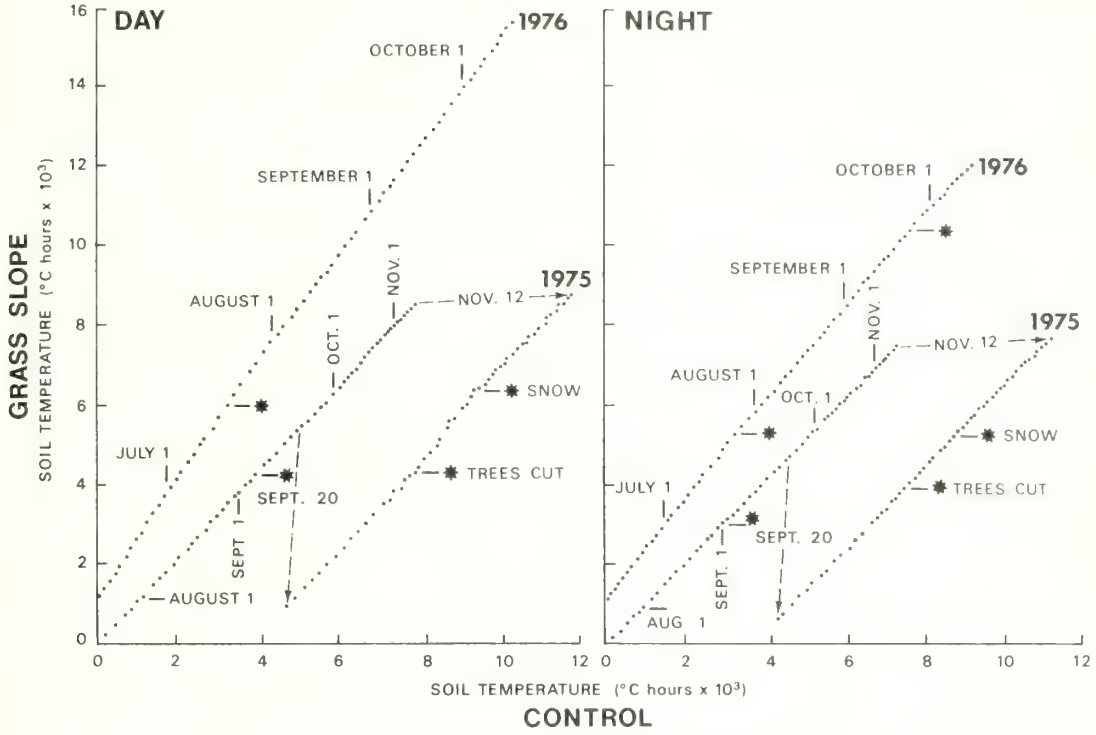


*Figure 7.--Double mass plot of accumulated degree hours for control soil and grass soil (1975 and 1976). Expanded portions are September 20, 1975, to November 12, 1975. Significant slope change is indicated by an asterisk.*

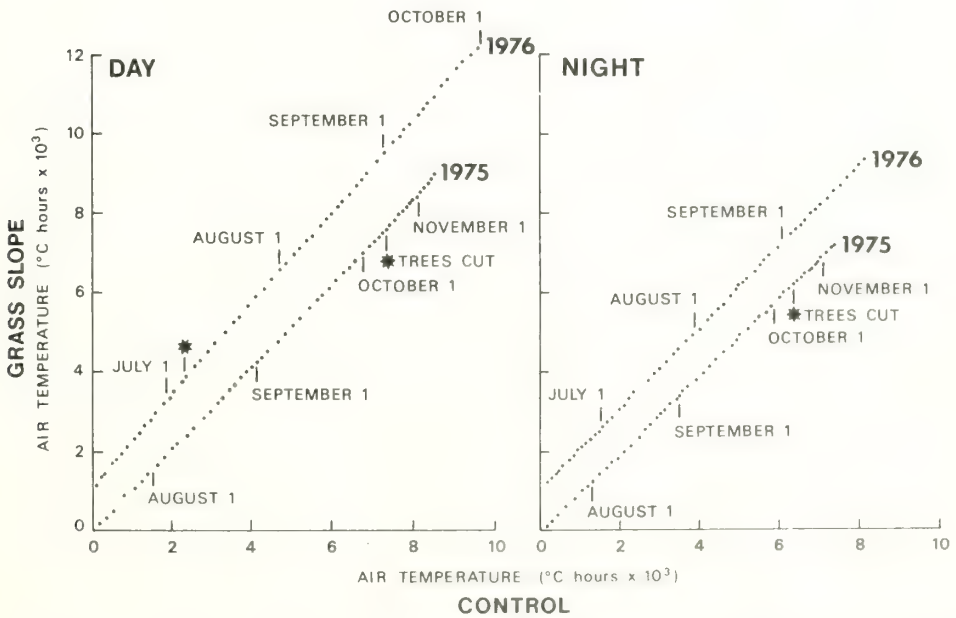


*Figure 8.--Double mass plot of accumulated degree hours for control air and grass air (1975 and 1976). Significant slope change is indicated by an asterisk.*

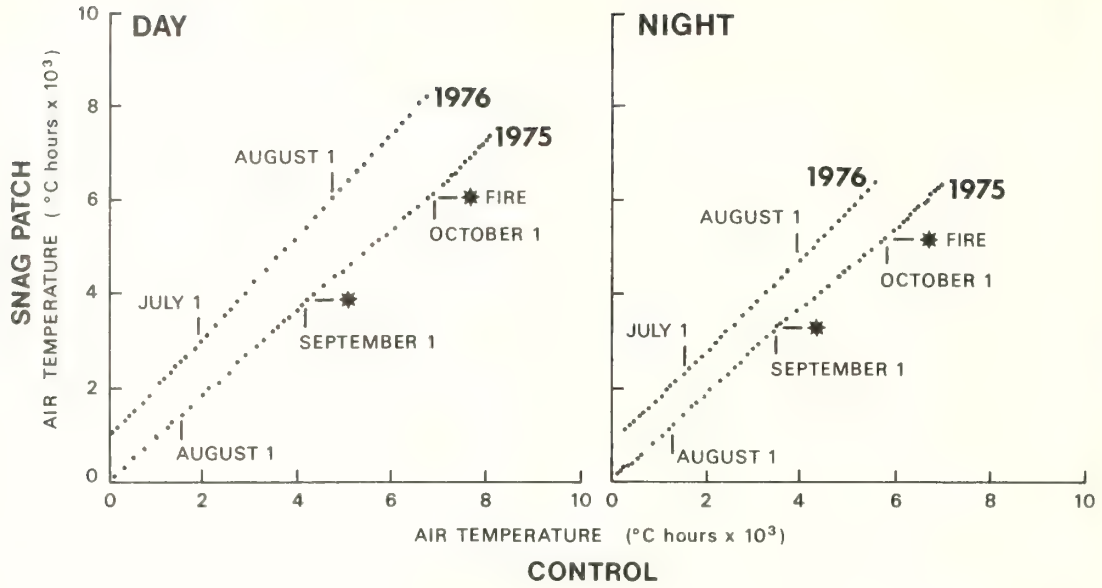


*Figure 9.--Double mass plot of accumulated degree hours for control air and snag air (1975 and 1976). Significant slope change is indicated by an asterisk.*

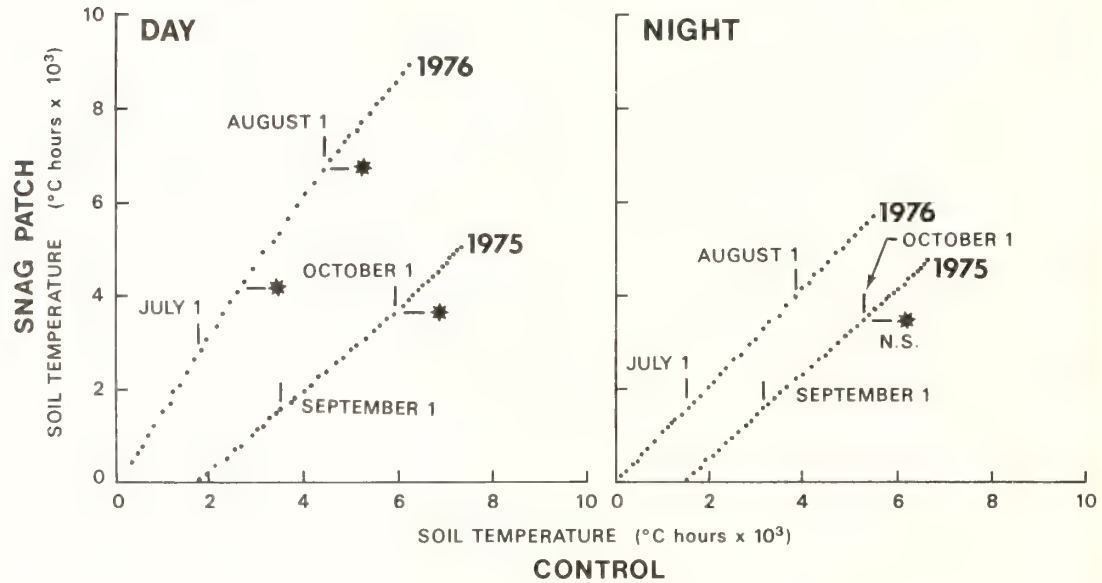


*Figure 10.--Double mass plot of accumulated degree hours for control soil and snag soil (1975 and 1976). Significant slope change is indicated by an asterisk.*

in figure 7, each point represents a 48-hour accumulation. If the rate of degree-hour accumulation progresses at two sites at some relatively constant rate, the plot is linear. If there is a statistically significant change in the slope, we can speculate on some changing condition(s) affecting the thermal regime at one of the sites.

On figures 7, 8, 9, and 10, the degree hours for both 1975 and 1976 are shown, and are divided into nighttime and daytime for soil and air. The comparison in each case is between the untreated control site and either the grassy slope or the snag thicket.

Tests were made for changes in slope when treatments were made (September 30 for the snag thicket and October 10 on the grassy slope) and at times indicated by a graphical discontinuity in the slope. Periods of testing are separated by asterisks on the plots. In general, all changes in slope shown on the daytime plots are significantly different ( $p = 0.01$ or better) in all combinations within a year and between the 2-year period. Similarly, most night comparisons are found to differ significantly in slope except for those noted as N.S. on the plots. A tabular summary of periods tested and slopes are shown in table 1.

Table 1--*Comparison between slope of degree hour accumulation (Grass Camp - 1975, 1976). Unless indicated as N.S. (nonsignificant), all possible slope comparisons differ significantly, p = 0.01 or better*

| Comparison | Period | Slope |
|---|---|---|
| Control Soil (Day) vs. Grass Soil (Day) | 7/22/75 to 9/5/75 | 1.0807 |
| | 9/6/75 to 10/9/75 | 1.0349 |
| | 10/10/75 to 10/20/75 | 1.3014 |
| | 10/21/75 to 11/12/75 | 1.0004 |
| | 6/4/76 to 7/22/76 | 1.5016 |
| | 7/23/76 to 10/19/76 | 1.3329 |
| Control Soil (Night) vs. Grass Soil (Night) | 7/22/75 to 8/27/75 | 1.0456 ← |
| | 8/28/75 to 10/9/75 | 1.0104 |
| | 10/10/75 to 10/20/75 | → 1.0731 |
| | 10/21/75 to 11/12/75 | 1.0012 N.S. |
| | 6/4/76 to 7/26/76 | N.S. 1.2851 |
| | 7/27/76 to 9/23/76 | 1.1896 |
| | 9/24/76 to 10/19/76 | → 1.0436 ← |
| Control Soil (Day) vs. Snag Soil (Day) | 8/9/75 to 9/29/75 | 0.8861 |
| | 9/30/75 to 10/28/75 | 1.0155 |
| | 6/4/76 to 7/12/76 | 1.6407 |
| | 7/13/76 to 7/29/76 | 1.4939 |
| | 7/30/76 to 10/25/76 | 1.2128 |
| Control Soil (Night) vs. Snag Soil (Night) | 8/9/75 to 9/29/75 | 0.9246 ← N.S. |
| | 9/30/75 to 10/28/75 | 0.9106 ← |
| | 6/4/76 to 10/25/76 | 1.0440 |
| Control Air (Day) vs. Grass Air (Day) | 7/17/75 to 10/9/75 | 1.0347 |
| | 10/10/75 to 11/12/75 | 1.0979 |
| | 6/4/76 to 7/6/76 | 1.2039 |
| | 7/7/76 to 9/29/76 | 1.1376 |
| Control Air (Night) vs. Grass Air (Night) | 7/17/75 to 10/9/75 | 0.9799 ← N.S. |
| | 10/10/75 to 11/11/75 | 0.9722 ← |
| | 6/4/76 to 9/29/76 | 1.0298 |
| Control Air (Day) vs. Snag Air (Day) | 7/17/75 to 9/1/75 | 0.9426 |
| | 9/2/75 to 9/29/75 | 0.8927 |
| | 9/30/75 to 10/28/75 | 1.0442 |
| | 6/4/76 to 8/28/76 | 1.1158 |
| Control Air (Night) Snag Air (Night) | 7/17/75 to 9/1/75 | 0.9411 |
| | 9/2/75 to 9/29/75 | 0.8340 |
| | 9/30/75 to 10/28/75 | 0.9919 ← N.S. |
| | 6/4/76 to 8/25/76 | 0.9908 ← |

1/ All possible comparisons are significant except those shown as N.S. with arrow brackets.

*Soil temperature in grass area.*--Of particular interest and illustrative of the sensitivity of this procedure is the expanded section for the period September 20, 1975, to November 12, 1975, on the control soil and grass soil double mass plot (fig. 7). Removal of shading vegetation allowed direct beam solar insolation to reach the soil surface. An immediate response (slope change) both day and nighttime occurred with the soil warming, only to be terminated as both grassy slope and control became snow covered on October 20. Ratio between control and grassy slope soil degree-hour accumulation for both night and day under the snow was virtually 1:1 (table 1).

During 1976, the temperature accumulation showed the higher energy input from the unobstructed sun; slope of the degree-hour accumulation is much greater than 1975 values. Other significant slope changes are noted on the plots for 1975 and 1976 in this figure 7 (and others) not identified with direct site treatments. These slope changes are discussed below relative to the changing temperature distribution within the individual 12-hour averaging periods.

*Air temperature in grass area.*--The day air temperature at this location (fig. 8) showed the effect of treatment (becoming warmer than control) but not of the snow cover. The grassy slope after snowfall maintained its slightly warmer day air temperature regime created by removal of the vegetation. The night air temperature (fig. 8), however, showed no significant slope change in degree-hour accumulation after treatment in 1975 compared to the control site.

In 1976 both day and night air temperatures at 0.5 m were consistently higher than control values.

*Air temperature in snag area.*--The snag thicket night air temperatures (fig. 9) continued the warmer than control trend established after the fire in 1975 with a nonsignificant slope difference between all of 1976 and the posttreatment 1975 trend. Snag day air temperatures are slightly warmer in 1976 than the terminal posttreatment period in 1975. Both posttreatment 1975 and 1976 periods follow a slope greatly different than in the pretreatment 1975 period.

*Soil temperature in snag area.*--After the fire in 1975, the night soil temperatures in the snag patch showed a nonsignificant but slightly negative slope change, a continuation of a prefire slope of less than 1:1. The night soil temperatures thus were generally cooler than the control prior to the fire and possibly even somewhat cooler after the fire. In 1976 control and snag soil temperature accumulations were essentially equal; significantly different from the 1975 values.

At the snag patch soil surface during day hours in 1976 (fig. 10), the temperature regime becomes more complex with two slope changes observed in 1976. Slopes for the degree-hour accumulations during the three periods in 1976 also differ significantly from the 1975 plot during both the pretreatment and posttreatment periods.

Figure 11 illustrates trends in the 7-day degree-hour accumulations for the snag patch and control soil for each 3-hour time period during the day. The most noticeable difference between these graphs is the obviously greater degree-hour accumulations in the snag patch during all day postfire periods. This accounts for the higher double mass slopes following the fire but does not account for the slope changes noted above. The changing shape of the plotted accumulation for the individual 7-day time periods indicates one of the factors controlling the slope variability seen for this (and other) locations. The control location shows a consistent 1500 hour

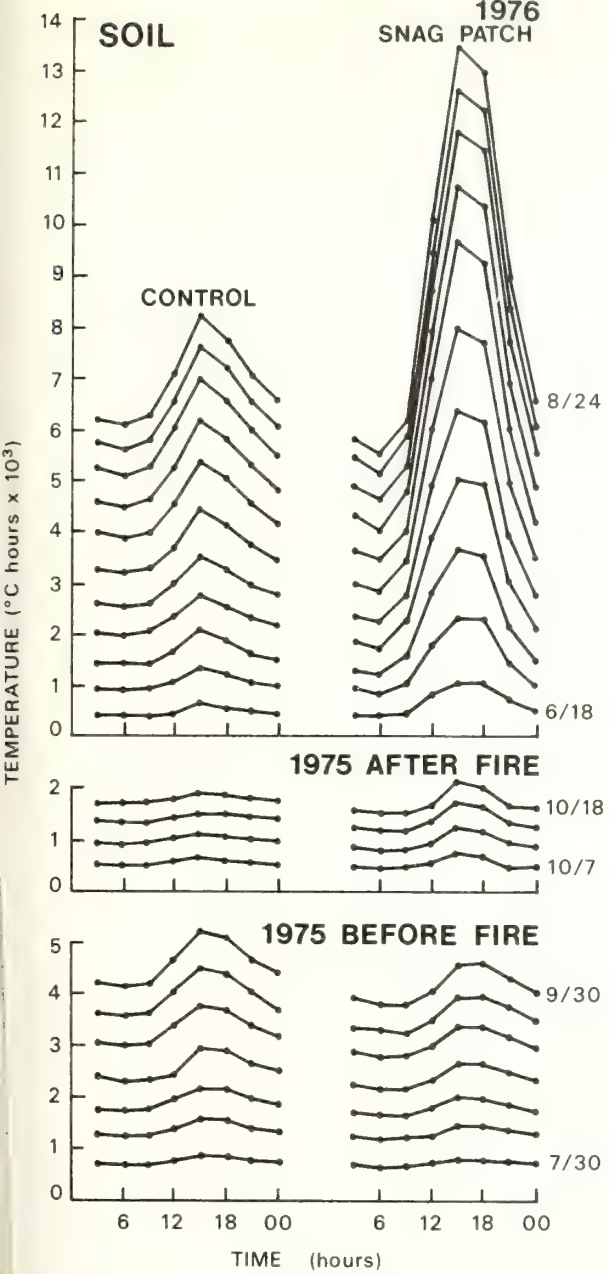


*Figure 11.--Cumulative degree hours per time period. Plotted for 7-day intervals for 1975 and 1976.*

maximum temperature accumulation through the 2-year period while the snag patch indicates accumulation for both 1500 and 1800 hours nearly identical for the pretreatment and 1975 posttreatment periods. During 1976, the 1800 hour snag patch degree-hour accumulation gradually retreats from the 1500 value; the slope of degree-hour accumulation in the double mass plot thus gradually decreases with time (fig. 10).

We also noted that the snag patch soil night temperature showed a slight but insignificant decline after the fire. The individual degree-hour accumulations for the 3-hour night periods show this decline as well. A general equivalence in degree-hour accumulation for the night period compared to control in 1976 was also noted. Table 1 shows a snag soil to control slope at night of 1.0440 to 1. Recognizing that this is the mean of all night values, if one observes the trend for a single 3-hour period, say 0300 to 0600 in figure 11, the slope of the relationship would have been strongly negative as shown from the depression of the 0300 and 0600 values in figure 11, compared to equivalent control values. It is the greater degree-hour accumulation during the other night periods, notably 2100 and 0000 hours that elevated the averaged night values.

## *FREQUENCY ANALYSIS OF 3-HOUR MEAN TEMPERATURES*

The double mass plot reveals minute changes in degree-hour accumulations accompanying the treatments. Although the plotted values can be converted to an average temperature between each point, much resolution is lost in the process. Occurrence of periods of below freezing temperatures or excessively high temperatures escapes notice. A frequency analysis of mean temperature for each 3-hour period supplies this type of information.

*Pretreatment period.*--Figure 12 represents pretreatment cumulative frequency distribution for air and soil temperatures for the three sites in 1975. The air temperature frequency distribution for the control and grass sites are remarkably similar. Limits on maxima and minima during the period of record are within the same $2^{o}$ C class interval. Examination of the actual number of cases within each temperature group (figs. 13 and 14)

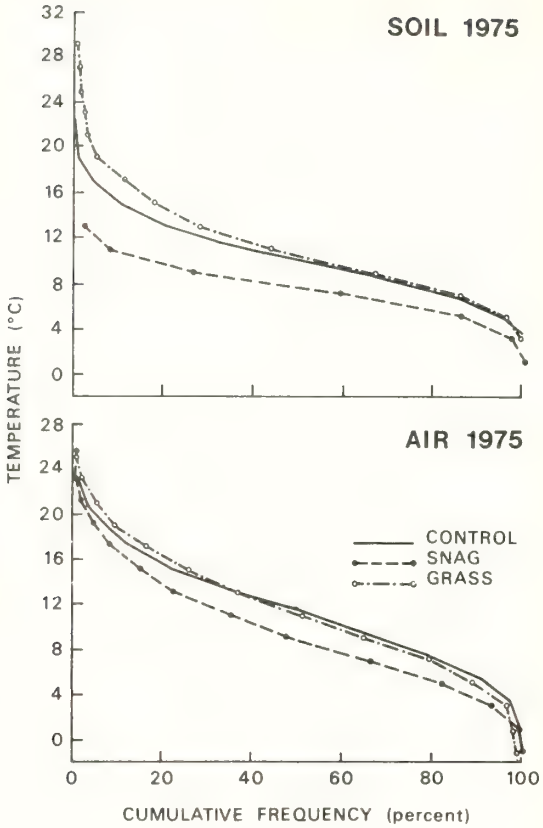


*Figure 12.--Cumulative frequency diagram for air and soil temperatures at three sites during the pretreatment period 2-degree class interval.*

at these sites indicates a slightly greater number of warmer periods at the grass site.

During the 1975 pretreatment period, the snag patch air temperatures had the same limits for the maximum and minimum values as the control and grass sites (fig. 12). Figures 13, 14, and 15, however, indicate a different distribution of temperatures during this period. Snag patch air temperatures were generally cooler; figure 15 shows most frequently occurring temperature to be within the 6-8° C class. Both the control and grass sites have a similar peak in this temperature class but a larger peak at 10-12° C (figs. 13 and 14). More below-zero air

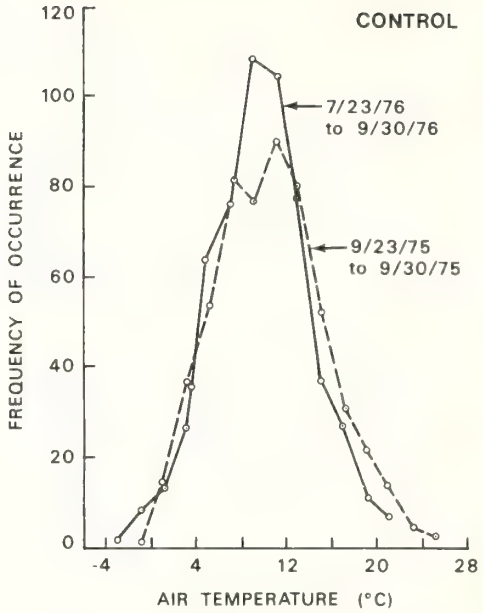


*Figure 13.--Control air temperatures-frequency distribution of 3-hour mean temperature (1975 and 1976).*

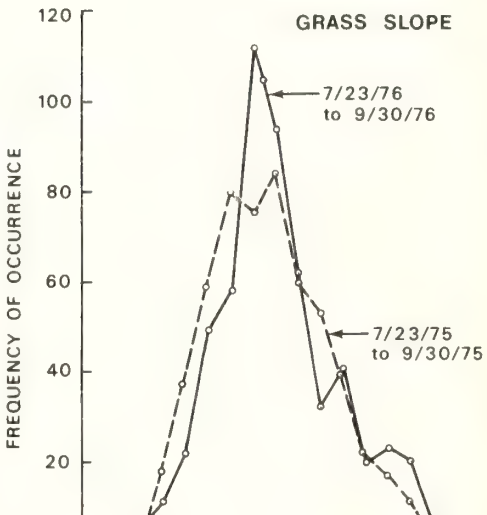


*Figure 14.--Grass air temperatures-frequency distribution of 3-hour mean temperature (1975 and 1976).*

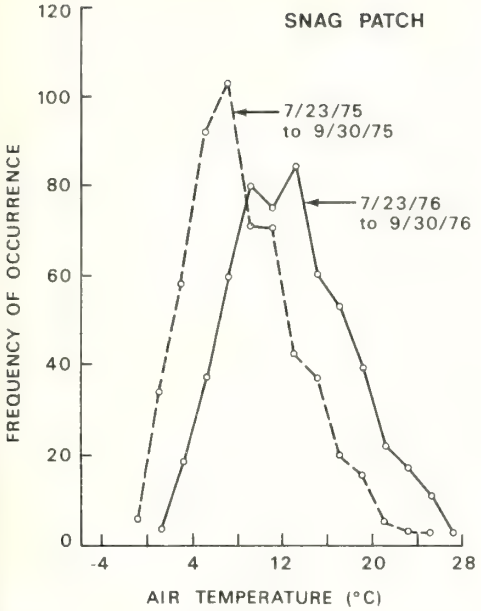


*Figure 15.--Snag air temperatures-frequency distribution of 3-hour mean temperature (1975 and 1976).*

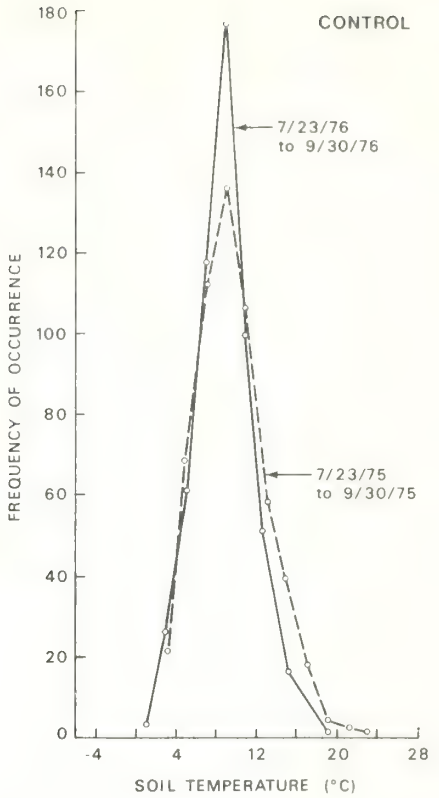


*Figure 16.--Control soil temperatures-frequency distribution of 3-hour mean temperature (1975 and 1976).*

temperatures were observed in the snag patch, six compared to two at the grass location and one at the control site.

Soil temperatures at these three locations were initially dissimilar. Figure 12 shows the initial pretreatment soil temperature frequency distributions, abstracted from figures 16, 17, and 18. Greatest pretreatment differences existed in the warmer temperature intervals. The dense layer of material near the surface of the snag patch prevented any direct insolation and restricted air exchange, while the soil surface at the grass site at times was intermittently exposed through the sparse canopy.

*After treatment.*--Figures 13 through 18 illustrate the treatment effects at these sites. Note particularly that in the control areas both air and soil temperatures in 1976 (figs. 13 and 16) have a more sharply

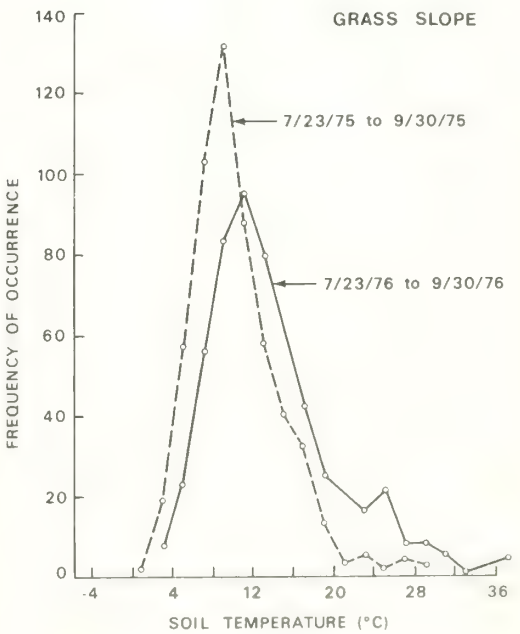


*Figure 17.--Grass soil temperatures-frequency distribution of 3-hour mean temperature (1975 and 1976).*

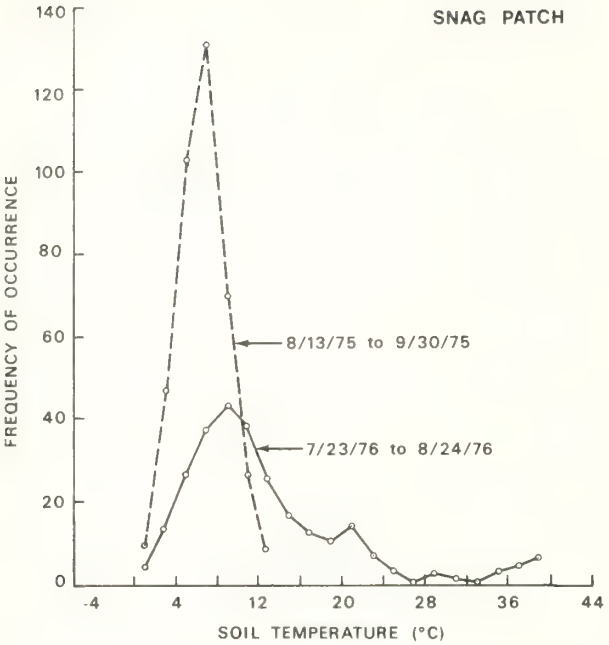


*Figure 18.--Snag soil temperatures-frequency distribution of 3-hour mean temperature (1975 and 1976). Note time period change for this figure compared to figures 13 through 17.*

peaked distribution (number of periods per temperature class) and a reduction in percentage occurrence of warmer temperature periods compared to 1975 (i.e. a cooler and less variable temperature history in 1976).

Treatment by fire or by shade removal reversed this trend in the snag patch and on the grassy slope. The air and soil temperature on the grassy slope (figs. 14 and 17) shifted towards higher values. More dramatic was the change in the snag patch thermal regime shown in figures 15 and 18. Air temperature maxima (snag and grass) were elevated into the next temperature class, from 24-26° C to 26-28° C; soil temperature maxima increased by 8° C on the grassy slope, by 26° C in the snag patch over pretreatment maxima.

Grassy slope air and soil temperature minima were also lowered in the posttreatment period. Snag air and soil temperature minima did not fall below pretreatment values.

## Discussion and Conclusions

Air temperature during burning in the snag thicket within the zone of heavy fuel concentration (the first several meters, with a maximum below 1.25 m) are within the ranges suggested by Davis (1959). Most of the snag thicket temperature measurements at the two lower levels, 0.25 m and 1.25 m, are within the 815-1 085° C (1500-1985° F) temperature range with no measurement exceeding 1 085° C. Our anticipation of a lower temperature burn and consequent emphasis on lower temperature measurements reduced resolution within the 815-1 085° C temperature range. Consumption of many fallen and some standing snags was accomplished at this burn intensity; but as figure 19 indicates, the burn killed all above-ground living material in the snag thicket, resulting in a newly created snag condition.

Air temperatures during burning at the one measurement location within the lodgepole pine stand were much lower. Fire at this location consumed the small accumulations of residue and the regenerating fir and spruce that would have been the future climax stand.

Prior to treatment, air and soil temperatures were found to reflect differing site exposures. Soil temperatures showed a greater pretreatment variablity than air temperatures even though the latter were measured as close to the surface as 0.5 m. The air temperature measurement represents the composite of energy exchange at the soil surface acting on an air column with a continuous but variable vertical and lateral heat exchange.

*Figure 19.--Snag patch conditions immediately following prescribed burn. Senior author examining temperature recorder in foreground.*

An uncoupling of the air and soil temperature regimes on the grassy slope was noted after the treatment (felling of selected trees in 1975). Day and night soil temperatures responded to the shade removal and later to snow cover. Air temperatures, at night and after snow cover, did not show a significant change in degree-hour accumulation, presumably due to the lateness of the season and general ineffectiveness of the local heating at this time of year. The change, however, was statistically significant throughout 1976.

Air temperature range was similar at all sites prior to treatment. The dissimilarity of soil temperatures both in range and persistence is evident in the temperature frequency diagrams. Limits in snags on maximum soil temperature to only 12-14$^{o}$ C compared to control 22-24$^{o}$ C and grass of 28-30$^{o}$ C suggest a restriction of soil heating by the mass of plant material at the snag site.

Treatment in the snag patch by prescribed fire in 1975 or by the felling of sunlight-obstructing vegetation at the grass site reversed the trend towards a cooler 1976 season shown in the control plot. A moderate increase in air temperatures occurred at the grass site, while air temperature in the snag patch and soil temperatures, both grass and snag, increased substantially. Increases of maxima in air temperature are damped by distance from the exchange surface (soil), but an overall temperature rise in the snag patch was evident. Soil temperatures increased by as much as 26$^{o}$ C in the snag patch

with maxima into the 38-40° C range. Since this is a 3-hour average temperature, the possibility of instantaneous temperatures in excess of these values can reasonably be expected. Soil temperatures have been reported above 67° C at similar elevations on fire-disturbed sites in the Entiat Experimental Forest. (Helvey et al. 1976).

The double mass plots of accumulated degree hours indicate the changing relationships that developed between control and treated plots. Statistically significant changes in the thermal regime due to treatment that might escape notice in other analyses are clearly shown. Some slope changes in the double mass plots, however, occurred other than at treatment time. In general, these changes reflect the changing angular relationships between a particular location and nearby (foliage) and distant (topographic) obstructions in the path of the direct solar beam. The principal effect is to modify through the season the receipt of energy and thereby change the rate and timing of local air and soil heating. This was effectively illustrated by the degree-hour accumulations for each 3-hour period at the soil surface in the snag patch.

Other effects can modify the ratio of degree-hour accumulation.

1. Averaging over 12 hours for degree-hour accumulation minimizes total response at a site.
2. Instability of the soil surface creates differences in local energy exchange. Within the snag patch, burned material and soil components are deposited and transported by gravity, wind, and water. The soil temperature sensor, for example, became partially exposed sometime prior to the first slope change in 1976. It was covered again in early June; this event helps to explain the observed slope change at that time. Some new or residual snags fell near the sensor locatic (fig. 19) during the period of record and modified local conditions. On the grassy slope, the surface is not static. The sparse vegetati cover offers insufficient protection to erosive forces
3. Seasonal regrowth or re-esta lishment of vegetation creat conditions of differential shading. A gradual reductic in the differences between sites will occur from reoccupation.

No measurements will be taken duri the 1977 season. After a suitable peri of time (3-5 years) depending on regrow remeasurement for a season will be considered. To preserve continuity, soil and air temperature sensors will be left in place during the interim.

Results of this study of the chang in thermal regime and continuation of the established trends should assist future evaluation of the effects of prescribed fire at this location. Othe investigators deal with successional trends on this and other nearby sites as participants in the overall study of the Grass Camp prescribed burn.[5/]

[5/] Study titles and principal investigators available from Forest Hydrology Laboratory, Wenatchee, Washington.

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GPO 986-234

Fowler, W. B., and J. D. Helvey.
1978. Changes in the thermal regime after prescribed burning and select tree removal (Grass Camp, 1975). USDA For. Serv. Res. Pap. PNW-234, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Thermal regimes at several locations are examined following prescribed burn or mechanical removal of shading vegetation. While the forested control location indicated a trend in 1976 toward cooler and less variable air and soil temperatures, treated locations responded vigorously to changing site exposure. Moderate increases in air temperature maxima at sensor height of 0.5 m were noted at treated locations while soil temperature maxima at 0.01 m increased by 8° C on the grass slope and by 26° C in the burned snag patch.

KEYWORDS: Temperature (soil), soil temperature, air temperature (-site, fire use, fire effects, prescribed burning, vegetal cover -)fire control.

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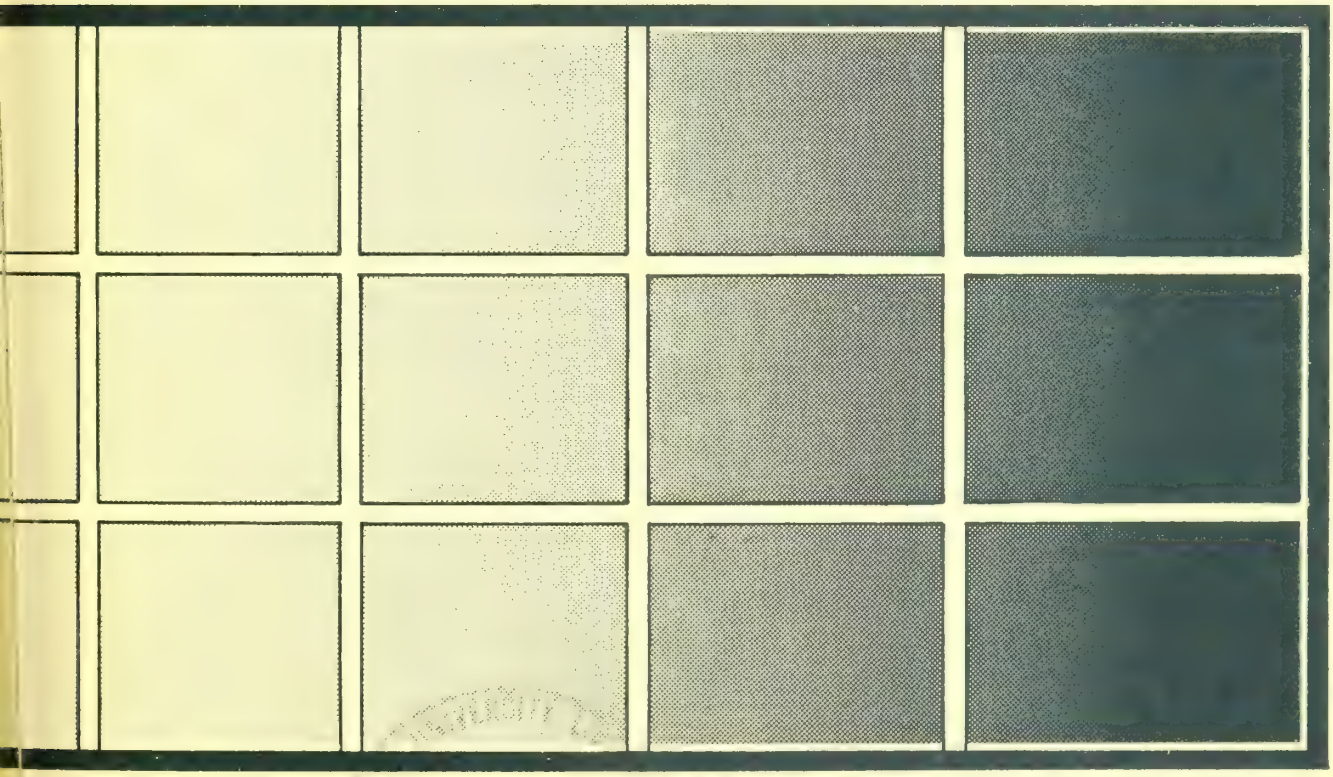
USDA FOREST SERVICE RESEARCH PAPER PNW-235
1978

# A TECHNIQUE for Predicting Logging Residue Volumes in the Douglas-Fir Region



James O. Howard

AUG 2

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

## *ACKNOWLEDGMENTS*

The cooperation and assistance of the following agencies is acknowledged:

The Bureau of Land Management, U.S. Department of Interior, provided financial assistance for the study and supplied timber contract data and personnel at the District level to help conduct field measurements.

The U.S. Forest Service, Region 6, assisted in supplying timber contract data and making available personnel on each National Forest to help conduct field measurements.

## *METRIC CONVERSIONS*

1,000 cubic feet = 28.3 cubic meters

1 cubic foot per acre = 0.070 cubic meter per hectare

1 inch = 2.54 centimeters

1 mile = 1,609.344 meters

# A TECHNIQUE FOR PREDICTING LOGGING RESIDUE VOLUMES IN THE DOUGLAS-FIR REGION

*Reference Abstract*

Howard, James O.
1978. A technique for predicting logging residue volumes in the Douglas-fir region. USDA For. Serv. Res. Pap. PNW-235, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This report presents results of a study using regression equations to predict the volume of logging residues before harvesting occurs. Procedures are discussed and equations presented for Bureau of Land Management and National Forest lands in western Oregon and western Washington.

KEYWORDS: Residue measurements, clearcutting systems, computation, Oregon (western), Washington (western).

*RESEARCH SUMMARY*

*Research Paper PNW-235*

*1978*

This report presents the findings of a study for determining the feasibility of predicting the volume of logging residue on clearcuts prior to harvesting. Data were collected from 160 clearcuts on Bureau of Land Management (U.S. Department of Interior) and National Forest (U.S. Department of Agriculture) lands in western Oregon and western Washington. Multiple regression techniques were used to develop equations relating preharvest stand and economic characteristics to measured residue volumes.

The regression procedure resulted in the development of individual equations for each of four Bureau of Land Management Districts in western Oregon. Separate equations were also derived for the National Forests in Oregon and those in Washington. Regression correlation coefficients ($R^2$) for the Bureau of Land Management equations ranged from 0.61 to 0.88, and were 0.44 and 0.51 for the National Forest equations.

Study results indicate that regression techniques as described have much potential for providing adequate estimates of logging residue volumes before harvesting occurs. Further testing and refinement of the procedure could provide the forest manager with a useful tool for making residue management decisions.

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## The Problem

Logging residues continue to be a major problem facing land managers in the Douglas-fir region. While volumes have been declining, logging residues are still being produced in rather large quantities. A 1969 study[1/] indicates volumes of 2,600 to 4,500 cubic feet per acre on Bureau of Land Management (BLM) and National Forest clearcuts. The volume on some areas was as high as 10,000 cubic feet to the acre. Reducing the volume of residues resulting from clearcut harvesting has been an objective of forest managers. Increasing pressures related to environmental impacts and decreasing timber supplies have intensified the problem in recent years.

An effective job of land management requires that the treatment of logging residues be an integral part of timber sale planning. Decisions concerning which of several residue treatment alternatives to use are frequently made prior to release of the sale for bidding. Thus the forest manager is faced with the problem of needing an estimate of the volume of residue before it is created. Personal experience has traditionally been the source of information for this decision.

The objective of this study was to determine the feasibility of using a regression equation approach to predict logging residue volumes prior to harvest. The guiding purpose is to provide the forest manager with a quantitative tool that will yield an acceptable estimate of the expected volume of logging residue for an individual clearcut unit. It is also felt that results from this study will make an important contribution to current research endeavors by identifying significant correlations between sale characteristics and residue volume.

The study was designed to produce regression equations utilizing information generally known to the forest manager prior to releasing the contract for bidding. These equations will produce an estimate of logging residue in terms of cubic feet per acre, thus giving the forest manager an objective basis for decisions related to residue abatement.

The study was conducted on BLM and National Forest lands in the Douglas-fir region of Oregon and Washington. All areas sampled were clearcut logged during calendar years 1972 and 1973. The line intersect method[2/] [3/] was used to obtain estimates of the volume of residue for the clearcut areas sampled.

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[1/] Howard, James O. Logging residue in Washington, Oregon, and California, volume and characteristics, USDA For. Serv. Res. Bull. PNW-44, 26 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

[2/] Warren, W. G., and P. F. Olsen. 1964. A line intersect technique for assessing logging waste. For. Sci. 10(3):267-276, illus.

[3/] Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14(1):20-26, illus.

## *Study Methodology*

In general, the study involved (1) selection of the independent variables and sample areas; (2) measurement of the logging residue on each clearcut area; (3) collection of data for the independent variables; and (4) processing the data in a regression program. This section of the report describes the process involved in determining the BLM and National Forest predictive equations.

The first step in the process was the selection of the independent variables. This was guided by a number of considerations: (1) data for each variable had to be readily available or collectable, (2) this information had to be available to the forest manager prior to release of the timber sale for bidding, and (3) each variable was assumed to have a direct or indirect correlation to the volume of logging residue. A preliminary list of variables was sent to each agency for review. Although these were the basic variables for which data was collected, combinations or exponential forms of these variables were also used in the analysis.

Listed below are the variables selected for the analysis:

(1) Stand age
(2) Gross cruise volume, per acre
(3) Percent stand defect
(4) Average slope percent
(5) Size of clearcut
(6) Average stand diameter
(7) Percent of exportable volume
(8) Estimated distance to nearest processing center
(9) Estimated haul distance on secondary roads
(10) Percent of whitewoods in stand
(11) Percent of western redcedar
(12) Appraised stumpage value
(13) Current utility lumber price index
(14) Current general lumber price index

Detailed definitions of these variables are included in the appendix. Many other variables were considered but were excluded from the analysis because of lack of data or because they were highly correlated to other variables.

A total of 160 clearcut areas, 80 each on BLM and National Forest[4/] lands, were randomly selected from all qualifying areas. The sample was allocated by BLM District or National Forest.[5/] By request of the BLM, 20 samples

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[4/] Due to a lack of certain data elements, only 79 clearcuts were included in the National Forest analysis.

[5/] All National Forests in western Oregon and western Washington were included in the study except the Rogue River, where no qualifying clearcuts were found.

were allocated to each of four districts. Not included in the BLM portion of the study were the Medford District and lands in western Washington. The Forest Service sample was allocated to each Forest on the basis of the proportion of the timber harvest in each Forest to the 1972 total. The next step in the study was to determine the population of clearcuts to be sampled. To be part of the population, each clearcut had to meet the following criteria:

(1) each area had to be 5 acres or more in size,
(2) the residue on the area could not have been piled or burned prior to measurement,
(3) logging had to be completed during calendar years 1972 and 1973, and
(4) cable yarding had to be employed over most of the area.

In addition, no unique sales, such as for salvage of fire or insect damage, were included in the sample population.

Each agency provided a list of all clearcut units that met the criteria of the study. The sample areas were randomly selected from these lists. Alternative samples were drawn in the event some of the primary areas failed to meet study standards at the time of residue measurement. A list of the sampled areas was sent to each agency to verify the status of each clearcut unit.

Fieldwork began after determination of the sample areas was completed. The volume of logging residue on each sample area was estimated using the line intersect method.[6/] Forty 200-foot transects were laid out on a systematic grid on each of the clearcut areas (fig. 1). All logging residue material intersected by these lines was measured. For this study, logging residue was defined as all dead material, regardless of origin, 3.5-inch d.i.b. or larger, at least 4 feet in length, and not rotten to the point of losing form (i.e., punky, spongy logs were not measured). Measurements recorded for each piece of residue were diameter inside bark, at the point of intersection with the transect (see fig. 2 in the appendix), and percent soundness on a chippable basis at the point of diameter measurement.

After completion of the fieldwork, data for the independent variables were collected from each agency. A final list of sample units, definitions, and examples of needed information was sent to each BLM District and National Forest. Date of initiation of logging was requested to provide a basis for office computation of the price index variables. After the data were collected, all information was keypunched in preparation for statistical analysis.

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[6/] Howard, James O., and Franklin R. Ward. 1972. Measurement of logging residue--alternative applications of the line intersect method, USDA For. Serv. Res. Note PNW-183, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

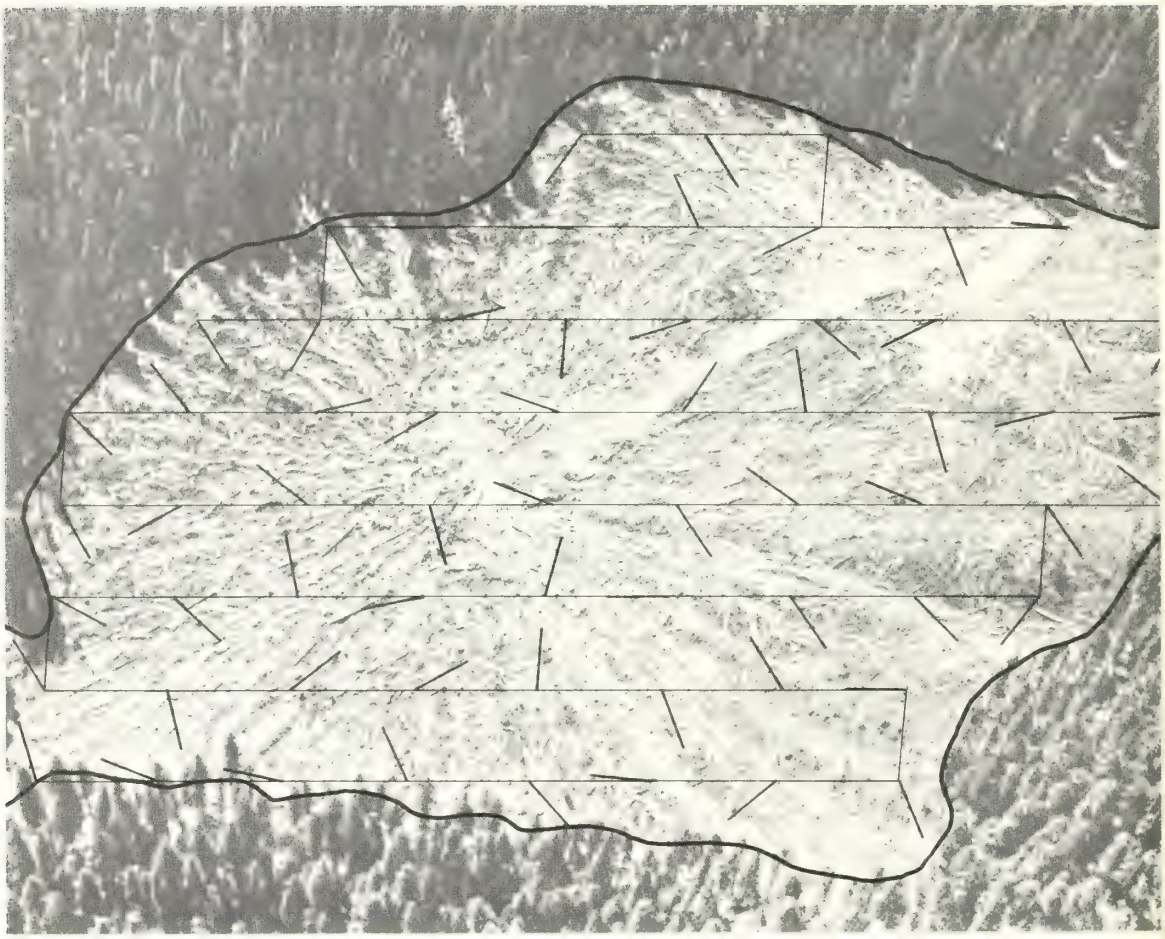

*Figure 1.--Symbolic representation of sampling grid applied to clearcut area.*

A multiple regression program, REX,[7] was used to derive a set of regression equations for each agency.[8] This program generates all possible combinations of the independent variables with a particular dependent variable. The combination with the smallest residual mean square error is selected as the best equation for that particular set of variables. Logging residue, the dependent variable in the analyses, is expressed in terms of cubic feet per acre. Both gross and net volumes of residue were tested.

In addition to the basic set of variables, various combinations, products, cross products, and exponential forms were analyzed. The samples were also arranged in various geographic strata to provide the best equations possible from the existing data.

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[7] Grosenbaugh, L. R. 1967. REX--Fortan-4 System. USDA For. Serv. Res. Pap. PSW-44, Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

[8] All clearcuts were given equal weight in the regression analysis.

## *Results of the Study*

Shown below are the proposed predictive equations for each agency. Although other combinations of variables and geographic areas were analyzed, these equations represent the smallest residual mean square error for each BLM District or National Forest. Logging residue is expressed in terms of cubic feet per acre, gross volume.[9/]

*Bureau of Land Management*

Coos Bay:

$$\text{Logging residue} = 19{,}863.7 - 84.726X_1 - 127.500X_2 - 53.153X_3 - 613.823X_4 + 18.248X_5 + 6.8931X_{10} + 0.55367X_{11} + 0.00105283X_{13}$$

Eugene:

$$\text{Logging residue} = 25{,}333.9 - 503.781X_1 + 74.135X_2 - 322.342X_3 - 214.939X_4 + 17.362X_5 + 6.14494X_{11} + 0.00444556X_{13}$$

Roseburg:

$$\text{Logging residue} = 4609.8 + 63.175X_1 - 118.786X_3 + 64.474X_4 + 43.321X_5 + 82.787X_6 - 74.687X_7 - 0.0693392X_{12} + 0.03454652X_{13}$$

Salem:

$$\text{Logging residue} = -40{,}774.0 + 792.213X_1 + 35.777X_2 + 629.868X_3 - 134.135X_6 + 107.196X_7 - 10.14438X_{11} - 0.01705336X_{13}$$

*U.S. Forest Service*

Western Oregon:

$$\text{Logging residue} = 2201.9 + 19.016X_3 + 46.953X_4 + 16.242X_5 - 13.711X_6 + 82.582X_8 + 21.672X_9 - 0.8673X_{10}$$

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[9/] Gross volume represents the total mass of a piece of residue, whereas net volume represents only the sound (chippable) portion.

Western Washington:

$$\text{Logging residue} = 2836.1 - 54.555X_2 + 22.705X_3 + 2.4385X_{10}$$

Examples of the use of these equations are included in the appendix.

The independent variables used in these equations are:

Basic variables[10/]

$X_1$ = clearcut size (acres)

$X_2$ = average slope percent

$X_3$ = cruise volume (thousand board feet per acre)

$X_4$ = percent stand defect

$X_5$ = appraised stumpage value (dollars)

$X_6$ = utility lumber price index

$X_7$ = general lumber price index

$X_8$ = percent western redcedar

$X_9$ = percent exportable volume

Definitions of these variables are included in the appendix.

Derived variables[10/]

$X_{10}$ = (average slope percent) x (percent stand defect)

$X_{11}$ = (clearcut size) x (cruise volume)

$X_{12}$ = (clearcut size) x (cruise volume) x (appraised stumpage)

$X_{13} = (\text{cruise volume})^3$

Table 1 gives some of the important statistics for each of the equations.

These equations were designed to yield an estimate of residue volume for a specific clearcut using information available during the normal timber sale process. Useful

10/ Basic variables are those for which data was collected; derived variables are some combination or form of the basic variables.

Table 1--*Statistical parameters for area equation*

| Areas | Number of sample units | $R^2$ | F-value[1/] | Mean-squared-residual | Standard error of estimate |
|---|---|---|---|---|---|
| BLM Districts: | | | | | |
| Coos Bay | 20 | 0.88 | 10.12 | .2066 | 592 |
| Eugene | 20 | .78 | 6.06 | .3490 | 918 |
| Roseburg | 20 | .61 | 2.19 | .6668 | 744 |
| Salem | 20 | .77 | 5.78 | .3623 | 1,061 |
| National Forests: | | | | | |
| Western Oregon | 52 | .51 | 6.54 | .5680 | 1,314 |
| Western Washington | 27 | .44 | 7.18 | .6368 | 565 |

[1/] The F-value is the total fit of all variables for each equation.

results from the equations are quite dependent upon the accuracy of the data for the independent variables. Thus, the integrity of the predictions can only be maintained by insuring accuracy and nonbias in the gathering of data for these variables.

In general these equations would not be used for areas with unique characteristics, i.e., with values of the dependent variables far exceeding the range of the sample units. For example, a 3-acre clearcut, tractor logged to salvage fire damage might yield unreasonable results if an equation was used to predict the volume of logging residue. Table 2, in the appendix, shows the range of values from the study for certain variables.

The signs of the coefficients of the independent variables do not necessarily indicate direct cause and effect relationships. What can be inferred from these signs is a positive or negative correlation between a particular variable and residue volume. For example, if the sign of a specific variable is positive, it indicates that the volume of residue will increase proportional to the value of that variable, other variables held constant. The statement cannot be made that this variable causes residue volume to increase. The paradox of the implication of cause and effect can be seen in the changing sign of the coefficient of a specific variable from equation to equation.

## Comments on the Findings

The results of this study indicate that multiple regression techniques can be used to derive equations for predicting the volume of logging residue for an individual

clearcut area. These equations can be used to assist in making residue treatment choices for a given sale, or to array estimates for all sales in an area to set priorities for treatment within a residue management program.

The reported equations were accepted as the best available within the constraints of the study. Further manipulations of the data might possibly have yielded improved results, however, the gains (increased $R^2$) would not warrant the added effort. The $R^2$ values for the BLM equations are much better than had been expected. Although not out of reason, the lower $R^2$ values for the National Forest equations are not readily explainable. Apparently, factors, or combinations of factors, exist that were not taken into account by the study. It is very probable that better results would be attained by following the study procedure for an individual National Forest. With the small number of samples for a single Forest, this hypothesis could not be tested in the current study.

Possibilities for improving these equations lie mainly in narrowing the geographic area of study, and including presently untested variables. Obviously, there are factors not examined in this study that affect the volume of residue created by clearcutting. This is evident by the amount of unexplained variation ($1-R^2$) in the current analysis. Many of these factors may, however, be unique to a limited area and not useful in a region-wide approach to residue prediction.

Regression analyses were also run using post-bidding independent variables and net volume of residue as the dependent variable. The use of post-bidding variables, such as bid price of stumpage rather than appraised stumpage, did not improve the equations. Rather, the opposite was true; $R^2$ decreased when these changes were introduced. Also, using the net volume of residue as the dependent variable led to lower $R^2$ values in most cases. This was expected because of the subjectivity involved in estimating the sound portion of residue material. The study focused on the gross volume, however, since most residue treatment decisions are related to the total mass of material rather than just the sound portion.

The equations developed in this study do not necessarily apply to timber sales in other geographic areas or for other ownerships within the study area. The biggest problem lies with the different natures of timber between areas and the different management objectives between owners. It is possible, however, that testing the equations in other areas might prove their acceptability for estimating logging residue in those areas.

Use of these equations to derive estimates of residue volume may be tempered by on-the-ground knowledge. In some areas, the forest manager may be aware of special circumstances

regarding a sale that indicate a modification of the predicted volume. For example, information concerning the potential purchaser of a sale makes it possible for the forest manager to adjust the predicted volume up or down. Unfortunately, in most cases the purchaser is not known prior to acceptance of a successful bid, thus hampering the use of this knowledge for pre-bid purposes.

Since results of this study indicate that regression equations can serve as predictors of clearcut residue volume, the next step is to test the equations in each of the study areas. This is a relatively inexpensive procedure and done to insure that conditions have not significantly changed so as to invalidate the relationships suggested by the equations and that characteristics of the samples are representative of the clearcuts in the area of use. The procedure for testing is similiar to that previously described. That is, the residue on a number of clearcuts is measured using the line transect method, data is collected for the independent variables; and this information is put into the predictive equation. The resulting estimates can then be checked against the measured volumes for accuracy. Large discrepancies for all test clearcuts might indicate the need to develop an equation unique to the particular area. If the predicted volumes are acceptably close to the measured volumes, the equation could be used as presented.

Due to the lower $R^2$ values for the National Forest equations, it may be necessary to develop new ones. This could be done at the Forest level, or for groups of Forests. Development of new equations would be relatively inexpensive in terms of time and money following the procedure outlined above. This process would also afford the opportunity to test new variables thought to be significant at the local level.

Once adopted, the equations should be updated periodically to account for changing conditions. This procedure would require little effort--especially if the regression program was maintained at a central location.

# Appendix

## DEFINITIONS

Following are the definitions and valuation units for each of the independent variables examined in this study. Only the basic variables are included since the derived variables are combinations, cross-products, or power terms of the basic variables.

*Stand age* is the estimated age of the stand to be cut to the nearest 10 years.

*Cruise volume* is the estimated gross volume per acre of the clearcut unit, to the nearest thousand board feet.

*Percent stand defect* is the estimated percent defect of the stand to be cut, to the nearest whole percent. This is reflected by $\frac{\text{gross cruise vol-net cruise vol.}}{\text{gross cruise volume}} \times 100.$

*Average slope percent* is the estimated average slope percent of the clearcut unit, to the nearest 5 percent. This may require that sample requirements be made. Care must be taken that the estimate reflects an overall average for the entire unit.

*Clearcut size* is the actual size of the clearcut unit, to the nearest whole acre.

*Average stand diameter* is the estimated average diameter b.h. of the stand to be cut, to the nearest inch.

*Export percent* is the percent of the stand volume that can legally be exported, to the nearest percent.

*Distance to processing center* is the estimated mileage to the processing center used in the appraisal, to the nearest 5 miles.

*Secondary road distance* is the estimated mileage of log hauling on nonpaved roads, to the nearest 5 miles.

*Percent whitewoods* is the estimated percent of total stand volume comprised of hemlock and true firs, to the nearest 5 percent.

*Percent western redcedar* is the estimated percent of total stand volume comprised of western redcedar, to the nearest 5 percent.

*Appraised stumpage* is the average stumpage value (appraisal) for the stand, to the nearest dollar; i.e., average dollars per MBF for all species.

*Utility lumber price index* is the computed price index for Utility-Economy grade lumber, to the nearest dollar. This index is computed by using information published by Western Wood Products Association (WWPA) in a monthly publication titled, "Monthly F.O.B. Price Summary Past Sales-Coast Mills." Prices are given for key items. The Utility price index used in this study is computed by taking 0.57 times the reported

price for Douglas-fir dimension, dry surfaced 4-inch Utility lumber plus 0.43 times the reported price for Douglas-fir dimension, dry surfaced Economy lumber. To account for the fact that these data are published with a one month lag, all values used in the study were for the month following initiation of the logging of the sample unit. For example, the January 1973 issue of the WWPA report shows Douglas-fir dimension, dry surfaced 4-inch Utility lumber at $113.71 per thousand board feet and the Economy at $46.11 per thousand board feet. The composite Utility index used in the study was 0.53 ($113.71) + 0.43 ($46.11) = $84.64 = $85; this value was used for all sample units logged in February 1973. This was done because at present, the most current data the forest manager would have would be for the previous month.

*Lumber price index* is the price for Douglas-fir dry Commons as reported by WWPA, to the nearest dollar per thousand board feet. The source for this price was the same as noted above. In this case the price is reported directly as Douglas-fir dry Commons, rather than being computed as was the Utility price index. The procedure for use of this price index is the same as described above. For example, in the January 1973 WWPA report the price for Douglas-fir dry Commons is $139.79 = $140. This figure was used for sample units logged in February 1973.

These variables are uniquely defined for this study. This is especially the case for the two "price index" variables. Better measures of prices may well be available for the local areas (Districts). If a new set of price indices can be obtained, they should be incorporated into the program in an attempt to improve the equations.

## *EXAMPLES*

The following examples are included to assist in the interpretation and application of the equations. The volume of logging residue is calculated for one sample unit for each agency. A description of the timber sale characteristics is shown along with the predicted volume and the volume measured in the study. As previously mentioned, logging residue is expressed in terms of cubic feet, gross volume.

### *BLM, Eugene District*

Equation: $R = 25{,}333.9 - 503.781X_1 + 74.135X_2 + 322.342X_3 - 214.939X_4 + 17.362X_5 + 6.14494X_{11} + 0.00444556X_{13}$

Sale Situation:

$X_1$ (size of clearcut) = 32 acres

$X_2$ (average slope) = 33 percent

$X_3$ (cruise volume) = 139 thousand board feet per acre (Scribner)

$X_4$ (stand defect) = 15 percent

$X_5$ (appraised stumpage) = $97 per thousand board feet

$X_{11} = (X_1)\ (X_3)$

$X_{13} = (X_3)^3$

Computation: $R = 25{,}333.9 - 503.781(32) + 74.135(33) - 322.342(139) - 214.939(15) + 17.362(97) + 6.14494(32)(139) + 0.00444556(139)^3$

Results: Gross volume of logging residue computed = 4,586 cubic feet per acre (observed = 3,823 cubic feet per acre)

*National Forest, Western Washington*

Equation: $R = 2836.1 - 54.555X_2 + 22.705X_3 + 2.4385X_{10}$

Sale Situation: $X_2$ (average slope) = 29 percent

$X_3$ (cruise volume) = 40 thousand board feet per acre (Scribner)

$X_4$ (stand defect) = 34 percent

$X_{10} = (X_2)\ (X_4)$

Computation: $R = 2836.1 - 54.555(29) + 22.705(40) + 2.4385(29)\ (34)$

Results: Gross volume of logging residue computed = 4,566 cubic feet per acre (observed = 3,685 cubic feet per acre)

Table 2 gives the range of values for certain variables by BLM Districts and National Forest areas. These values are taken from the sample data used to derive the equations. These data are shown to assist the forest manager in evaluating the appropriateness of applying the equation to a specific clearcut unit. As previously mentioned, use of the equations should be restricted to clearcut units with characteristics that do not greatly exceed the range of values for the independent variables and study criteria.

Figure 2 shows the location for diameter measurement for a piece of residue material intersected by a line transect. Special cases are shown for lines intersecting the ends of a log. Figure 2(A) shows the intersected face of the log, the place where the defect estimation is made for net volume estimates.

Table 2--*Range of values for selected variables used in predictive equations*

| Variable[1/] | Bureau of Land Management equations | | | | National Forest equations | |
|---|---|---|---|---|---|---|
| | Coos Bay | Eugene | Roseburg | Salem | Western Oregon | Western Washingtc |
| Clearcut size (acres) | 5- 82 | 9- 73 | 9-73 | 10- 66 | 2/ | 2/ |
| Average slope (percent) | 35- 94 | 12- 63 | 2/ | 15- 71 | 2/ | 12- 77 |
| Cruise volume (thousand board feet) | 50-264 | 52-139 | 20-70 | 49-120 | 28-146 | 31-105 |
| Stand defect (percent) | 14- 48 | 7- 16 | 18-48 | 2/ | 6- 52 | 2/ |
| Western redcedar (percent) | 2/ | 2/ | 2/ | 2/ | 0- 15 | 2/ |
| Exportable volume (percent) | 2/ | 2/ | 2/ | 2/ | 0- 80 | 2/ |

1/ Does not include price variables or derived variables.

2/ Variable does not appear in the equation for this area.

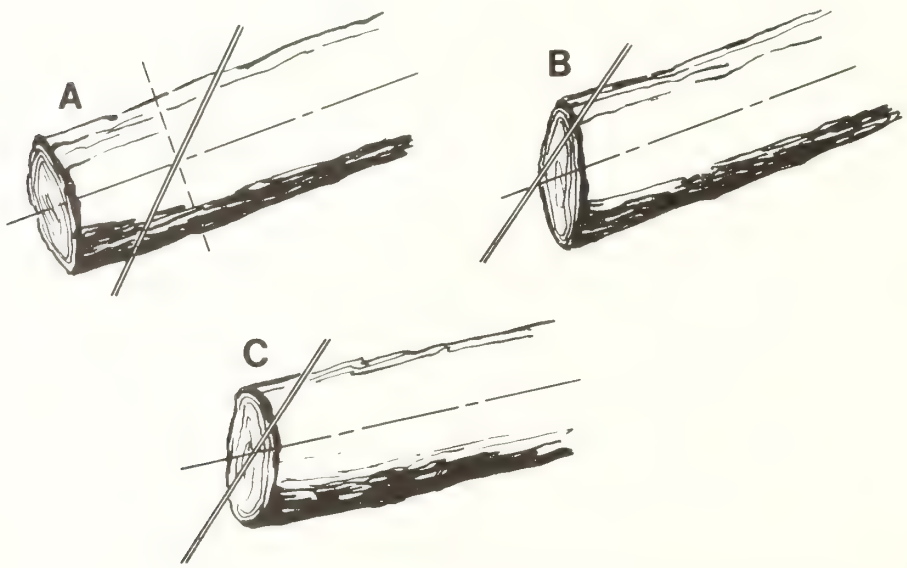


*Figure 2.--Location of diameter measurement: (A) each piece is counted and diameter is taken at intersection of transect with centerline; (B) piece is not counted; (C) count every other piece and take diameter at end of piece.*

Howard, James O.
1978. A technique for predicting logging residue volumes in the Douglas-fir region. USDA For. Serv. Res. Pap. PNW-235, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This report presents results of a study using regression equations to predict the volume of logging residues before harvesting occurs. Procedures are discussed and equations presented for Bureau of Land Management and National Forest lands in western Oregon and western Washington.

KEYWORDS: Residue measurements, clearcutting systems, computation, Oregon (western), Washington (western).

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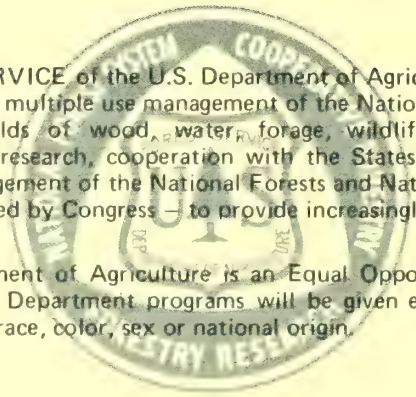

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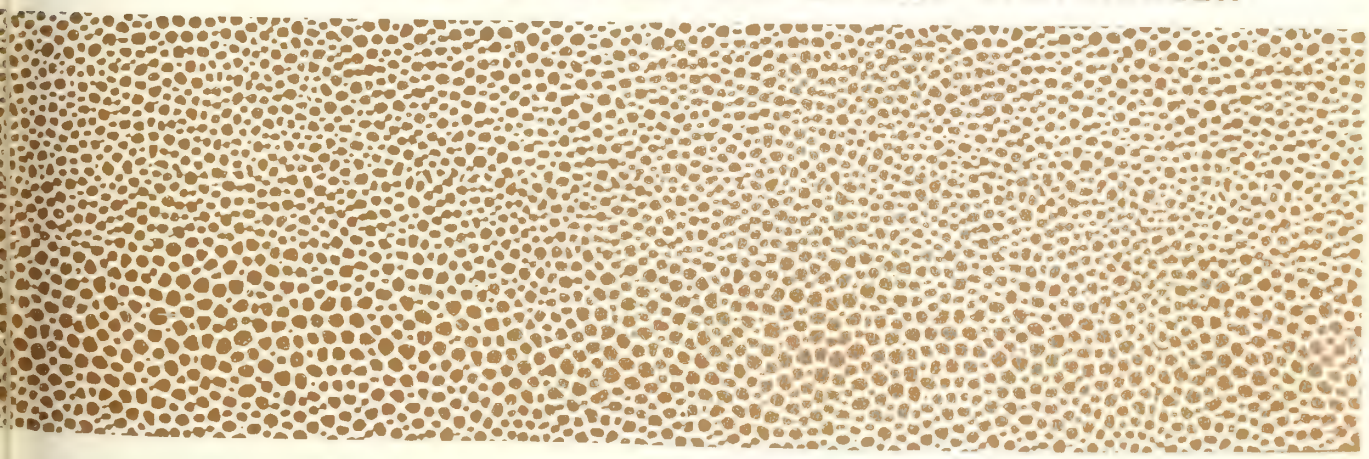
# PHYSICAL and CHEMICAL PROPERTIES of some BLUE MOUNTAIN SOILS in NORTHEAST OREGON

J. MICHAEL GEIST and GERALD S. STRICKLER



PACIFIC NORTHWEST FOREST and RANGE EXPERIMENT STATION
FOREST SERVICE U. S. DEPARTMENT of AGRICULTURE
PORTLAND, OREGON

# PHYSICAL AND CHEMICAL PROPERTIES OF SOME BLUE MOUNTAIN SOILS IN NORTHEAST OREGON

*Reference Abstract*

Geist, J. Michael, and Gerald S. Strickler.
1978. Physical and chemical properties of some Blue Mountain soils in northeast Oregon. USDA For. Serv. Res. Pap. PNW-236, 19 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Soil properties of 57 forested locations were characterized and categorized by parent materials and vegetation. Properties were compared and interrelated, and their management implications were discussed. Data will serve as a basis for comparison with other soil-vegetation systems and for assessing environmental impacts.

KEYWORDS: Soil properties (physical), soil properties (chemical), soil management, plant-soil relations, volcanic ash soil, Oregon (Blue Mountains).

## *RESEARCH SUMMARY AND MANAGEMENT IMPLICATIONS*

*Research Paper PNW-236*

*1978*

Physical and chemical properties of soils in 57 forested locations spanning a wide range in vegetation and climate were characterized. Results were stratified by volcanic ash and basalt parent materials or by overstory tree species. These data did not arise from a random sampling of a defined population of soils and are thereby limited in their extrapolation. But they remain useful to soil scientists, hydrologists, and others in determining management alternatives, assessing management influences, writing impact statements, etc. Virtually all properties are probably related to the productivity of the localities studied; another paper on these relationships is planned.

Volcanic ash materials were found to have high water storage potential and are capable of yielding comparatively large proportions of this water to plants within low soil moisture stress limits (0.1-1.0 bar). This property is important to ecological and productivity considerations since moisture storage is especially critical to growth in areas like eastern Oregon with little summer precipitation.

The bulk densities of ash-derived soils were low and averaged lower than basalt-derived soils at all sampling depths. Densities

increased down the profile in both soil groups. These data will serve as reference points in determining if, where, how long, and how much compaction is occurring with various management activities.

Significant interpretive and quantitative errors can occur when soil chemical properties are compared without considering inherent differences in physical properties (bulk density, thickness of soil, coarse fragments, etc.). This was evident in some of the data when compared on the basis of a percentage or milliequivalents per 100 grams versus amounts per unit area.

Certain generalities do not apply to ash and ash-influenced materials. Broadfoot and Burke's (1958) reported bulk densities and water-holding capacities for soils of similar textures should not be applied in eastern Oregon (and other areas with ash-influenced soils) because of the large discrepancies between their findings and those reported here.

Coarse fragments, which significantly affect many soil properties, were more abundant in basalt-derived soils and were more common in subsoils of both ash and basalt-derived soils.

Keeping topsoil in place is a management objective supported by many of the findings. Most nutrients are disproportionately higher in the surface soil--frequently about two-thirds of the organic matter and total nitrogen occurred in the upper 30 cm of the profile. Moisture storage is usually greatest in surface soils as well. Soil erosion or soil displacement by machines in skidding, constructing landings, piling slash, preparing sites, (dishpanning), etc., which removes as little as 7.6 cm (3 in) of topsoil from the producing area, sacrifices 2.7 cm of potential water storage (29,000 gallons per acre) in basalt soils and 3.4 cm (36,000 gal/acre) in ash soils. If we add significant nutrient losses to this, it is easy to understand why topsoil conservation is an important management objective with every management entry, regardless of purpose. Some detrimental management influences are additive over time; thus, seemingly small individual effects become magnified.

Several localities in the study areas are known to have nutrient deficiencies in nitrogen and sulfur. Since the supply of these nutrients is strongly linked to soil organic matter, conservation of topsoil will aid in minimizing deficiencies where they now exist and curbing the creation of additional deficient localities.

Buried soils beneath ash layers are sometimes high in clay and restrictive to root growth. When ashy overburden material is partially removed mechanically or by erosion processes, a tree-producing site may be transformed into a grassland or shrubland because of reduced water storage capacity. Some recent failures in artificial reforestation appear to be the result of such a situation.

In their natural state ash- and basalt-derived soils are relatively stable and resist erosion. Ash soils are easy to displace by mechanical equipment and, when protective cover has been removed, both soils can readily erode. Both soils are also subject to slumping and slides during wet periods when undercut, even on moderate slopes.

Sharp gradients in profiles require the adoption of exacting standards in sampling prescribed depth increments of soils. Lax sampling controls can invalidate comparisons with data reported here and elsewhere. Strict attention to methodology used in analyses is necessary since some methods do not yield parallel results.

Total soil depth measurements are best obtained by digging a soil pit or using a screw auger at several points. Bucket augers give lower values, particularly in soils containing abundant coarse fragments.

Study results indicated the necessity to consider stratification criteria such as parent material, vegetation, and precipitation in contrasting soil properties. Such stratification is critical to detection and eventual understanding of the various soil-plant relationships. For example, volcanic ash soils supporting a spruce-fir overstory had higher amounts of organic matter, higher total nitrogen, and lower cations than ash soils supporting other species. Whether the differences were due to associated trees, ground cover species, and/or differences in climate is not certain until further comparisons without confounding factors are made. Regardless of cause, these data are valuable for the uses discussed and will become increasingly valuable.

## Introduction

Quantification of the physical and chemical properties of forest soils is a relatively young effort. Much of the available soil survey data are qualitative, although this is changing as needs for quantitative information increase. This paper reports the results of field investigations and laboratory analyses of soils at 57 study locations in the Blue Mountains in northeastern Oregon. An earlier paper (Geist 1974) contained only data on chemical concentrations for a subset of these locations. The earlier data and that subsequently collected are combined in this paper. Chemical data have also been expressed in units of kilograms per hectare which reflect physical influences on soil chemistry. Thus, this paper provides two reference bases for chemical data and a variety of soil physical data. Portions of both physical and chemical data were also reported by Geist (1973).

Sampling was not done at random within a designated population because soil populations of the Blue Mountains are yet undefined. Thus, the extrapolation of the results are limited to that part of the soil population defined by the parent materials, soils, vegetation, and climatic conditions described in this paper. The data contribute to a better understanding of the soil-vegetation systems studied. This increased knowledge will help resource managers assess and, we expect, predict the various impacts from present and planned land use.

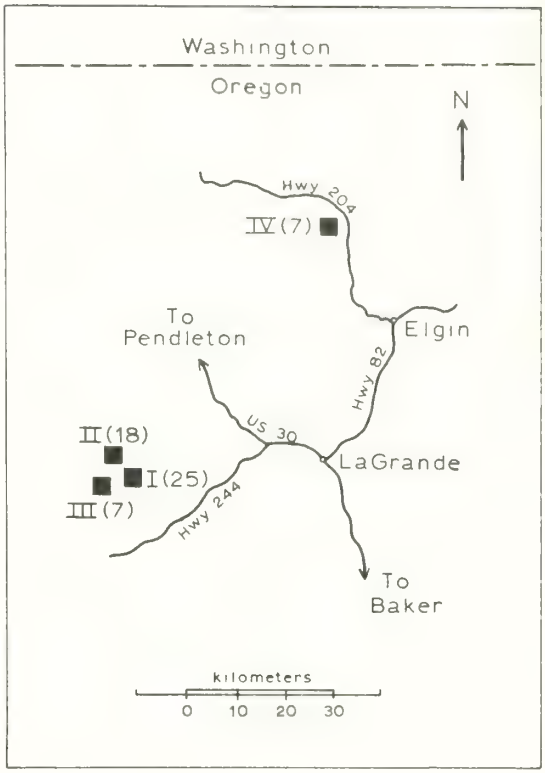



*Figure 1.--Study areas I-IV. The number of study locations in each area is shown in parentheses.*

## Study Area and Soils

Study locations were on forested portions of the Wallowa-Whitman and Umatilla National Forests near La Grande, in Union and Umatilla Counties (fig 1). Most locations (areas I, II, III) occurred in or near the Starkey Experimental Forest and Range. Two soil parent materials dominated: (1) silt-size volcanic ash originating from Mount Mazama eruptions (Harward and Youngberg 1969) and (2) basalt. Mazama ash soils commonly support lodgepole pine (*Pinus contorta* Dougl.), grand fir (*Abies grandis* Dougl. Lindl.), western larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmannii* Parry), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Basalt soils support Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and ponderosa pine (*Pinus ponderosa* Laws.), a seral dominant maintained by fire.

Elevations ranged from 1 265 to 1 447 m in areas I, II, and III, and from 1 402 to 1 578 m in area IV.

Precipitation is estimated to range from 50 to 60 cm in areas I, II, and III, and from 90 to 125 cm in area IV.

Soils derived from 50 cm or more of volcanic ash over an older buried soil were of the Tolo (Typic Vitrandepts[1]) and Helter series (Entic Cryandepts). Soils formed primarily from basalt residuum or colluvium were frequently of the Klicker series (Ultic Argixerolls) which range from 50 to 100 cm to bedrock. Shallower soils of similar origin to those described were encountered in the study. These shallower soils were formerly classed within the Tolo and Klicker series concepts,[2] but they are excluded from current series interpretations. Renaming of these soils or recognition of intergrades, etc., has not been resolved. Soil names in this report are uncorrelated and must be considered tentative.

Tolo and Helter soils most commonly occur on north- and east-facing slopes, but they also occur on forested ridgetops or plateaus. Klicker soils generally occupy south and west slopes and ridge margins.

Detailed descriptions of soils are available from the Starkey Soil Survey (Range and Wildlife Habitat Laboratory, La Grande, Oregon); these descriptions are being updated into the new taxonomy. Hence, only general descriptions will be given here.

Tolo soils consist of a silt loam ash layer of weak coarse to thin platy surface structure, grading to massive structure at the buried soil contact. The ash material is soft and very friable throughout. Moist color grades from very dark grayish brown (10 YR 3/2) or dark brown (10 YR 4/3) in surface portions to pale brown (10 YR 6/3) or very pale brown (10 YR 7/4 and 8/3) in lower portions. These moist colors generally lighten markedly during drying.

The buried soils, derived mostly from basalt in areas I, II, and III, are lighter and redder, with 7.5 YR hues common. They have better developed structure which is moderate, medium subangular blocky but occasionally strong fine prismatic, firm to very firm, with textures of silty clay loam to clay loam. Ash layers are 50-100 cm thick within the series, and bedrock exceeds 100 cm. Few coarse fragments occur in the ash layer but rather high percentages may occur in the buried portion.

Helter soils are similar to Tolo soils but have thicker A1 horizons (to 15 cm); and although their elevational occurrences overlap, Helter soils extend to higher elevations. They were common in area IV. Buried portions were mostly of andesitic origin and were probably influenced by loess.

Klicker soils are primarily of basaltic origin but may be ash-influenced in the surface. Surface and subsurface colors are in the redder hues (7.5 and 5 YR). Structure ranges from weak fine platy or weak fine granular in the surface soil to weak or moderate fine subangular block in the subsoil. Texture ranges from loam or silt loam in the surface soil to silty clay loam or clay loam in the subsoil. The profile may be strongly affected by gravels and cobbles which are generally more abundant in the lower portion. Influence of coarse fragments is greater on steeper slopes

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[1]Soil Survey Staff. 1972. Soil series of the United States, Puerto Rico, and the Virgin Islands: Their taxonomic classification. 376 p. Soil Conserv. Serv., U.S. Dep. Agric.

[2]Soil Survey, Starkey Experimental Forest and Range, Union and Umatilla Counties, Oregon. 1960. Soil Conserv. Serv. and Pac. Northwest For. and Range Exp. Stn., USDA For. Serv. Mimeogr., 32 p.

## Methods

Sample locations were established within homogeneous vegetation units with uniform surface relief. At each location a bucket auger was used at five random points along a 30-m transect to assess soil depth and to obtain soil samples. Sampling intervals were 0-15, 15-30, 30-60, 60-90, 90-120, and 120-150 cm unless soil depth was limiting. A screw auger was also used to assess total soil depth at the same random points. The five samples from the same depth interval were composited and mixed. Mixed materials were air dried and the soil fraction (less than 2 mm) was separated for chemical analysis. Both size fractions were then weighed.

A soil pit was excavated at each location, soils were described, (Soil Survey Staff 1951) and single, 100-$cm^3$ undisturbed soil cores were extracted from pit walls at the midpoints of sampling intervals. Cores were wrapped in aluminum foil to avoid drying effects (Forsythe and Vazquez 1973) and refrigerated. Moisture content of cores at 0.1-, 1-, and 15-bar soil moisture stress was determined at room temperature by pressure plate apparatus. Graduated outflow tubes were used to assure equilibrium. Bulk density of the soil fraction was also calculated from cores. The weight and volume of particles greater than 2 mm (coarse fragments) were deducted from core data; a particle density of 2.65 $g/cm^3$ was assumed. Dry weight of each core was measured after ovendrying. When core samples were not obtained at lower profile depths because of excessive stoniness, data from the nearest depth core in the same profile were used.

Volume percentages of coarse fragments in the soil profile greater than 3-cm diameter were visually estimated when soil descriptions were made. Coarse fragments between 3-cm and 2-mm diameter were included in auger samples and their percentages were initially determined by weight; their volume percentages were then calculated, after allowance was made for soil and larger coarse fragments. Particle sizes of the soil fraction of bucket auger samples were analyzed by hydrometer technique after organic matter was destroyed by hydrogen peroxide.

Chemical analyses of soils included organic matter by the Walkley-Black method, total nitrogen by Kjeldahl method (Jackson 1958), extractable sodium and potassium by flame photometer, and extractable calcium and magnesium by versenate titration (U.S. Salinity Laboratory Staff 1954). Extractable cations of more recent soil samples were determined by atomic absorption spectrophotometer. Available phosphorus was determined by the sodium bicarbonate extraction technique (Watanabe and Olsen 1965), and soil reaction (pH) was measured in 0.01-molar calcium chloride (Black 1965). Carbon-nitrogen ratios were computed; organic matter was assumed to average 58-percent carbon content. Calcium-magnesium ratios were calculated from extractable quantities of each.

When mean nutrient concentrations (percentages or milliequivalents per 100 g) or amounts were calculated for a sample interval, zeros occurring because of shallow soils were not included in the mean but were included for mean cumulative amounts. The same procedure was used in computing water concentrations (percentages) and amounts (centimeters).

Data from physical and chemical soil analyses were grouped by two surface parent materials, ash (regardless of buried soil origin) and basalt, or by one of four overstory timber types: ponderosa pine (PP), mixed conifer (MC), lodgepole pine (LP), and spruce-fir (SF). Except for the SF, this grouping reflected the dominant overstory species. The SF included any study location where Engelmann spruce and subalpine fir were present. The LP and SF groups were strongly associated with ash-derived

soils and the PP, commonly seral to Douglas-fir, with basalt-derived soils. The MC group was most commonly associated with ash, but it also occurred on basalt soils. In this group Douglas-fir or grand fir were commonly dominant or were codominant with PP and western larch.

## Results

The strong associations of overstory groups and soil parent materials is illustrated by the following: The PP group contained 18 of 19 soils derived from basalt, the MC had 16 of 20 soils derived from ash, and the 11 soils supporting LP and the 7 soils supporting SF were derived from ash.

### *PHYSICAL PROPERTIES*

Soil textures are closely alined with parent material groups (table 1). Ash soils are dominantly silt loam in texture throughout the ash overburden, then grade into loam in the buried soil. The basalt soils are dominantly loam in the surface and grade into clay loam and clay textures in lower layers.

Clay percentages and associated standard deviations increase downward in both ash and basalt soils, though not at equal rates (table 2). The influence of buried soils is evident at 60-90 cm in ash soils where the mean clay content increases 9 percent over that in the 30- to 60-cm interval. The corresponding increase in basalt soils is 4 percent.

Bulk density is strongly associated with parent material and averages lower in ash soils than in basalt soils at corresponding depths (table 2). Densities increased in both groups at deeper sampling intervals. Variability in bulk density tended to increase with depth but was relatively low in surface layers.

Similar low bulk densities for volcanic ash were reported in Oregon by Ross[3]--0.61-0.68 g/cm$^3$, Simonson and Shearer (1971)--0.84, and Lincoln

[3]Ross, Richard N. 1971. Snow and soilwater response to logging. M.S. thesis. Colo. State Univ., Fort Collins. 85 p.

Table 1--*Frequency of soil textures by sampling intervals for basalt and ash soils*

| Sampling interval | Textural class | | | | Total number of samples |
|---|---|---|---|---|---|
| | Clay | Clay loam | Loam | Silt loam | |
| Centimeters | - - - - - - - Percent - - - - - - - | | | | |
| Basalt soils: | | | | | |
| 0-15 | 0 | 0 | 95 | 5 | 22 |
| 15-30 | 0 | 9 | 86 | 5 | 22 |
| 30-60 | 0 | 44 | 56 | 0 | 18 |
| 60-90 | 17 | 33 | 50 | 0 | 6 |
| Ash soils: | | | | | |
| 0-15 | 0 | 0 | 0 | 100 | 35 |
| 15-30 | 0 | 0 | 0 | 100 | 35 |
| 30-60 | 3 | 0 | 3 | 94 | 35 |
| 60-90 | 3 | 3 | 59 | 35 | 29 |

Table 2--*Means and standard deviations of some physical properties in ash and basalt soil groups by sampling interval*

| ampling nterval | Ash soils[1] | | | Basalt soils[1] | | |
|---|---|---|---|---|---|---|
| | n | $\bar{X}$ | s | n | $\bar{X}$ | s |
| imeters | | | | | | |
| | | CLAY CONTENT | | | | |
| | | Percent by weight | | | Percent by weight | |
| -15 | 35 | 10 | 2 | 22 | 20 | 3 |
| -30 | 35 | 9 | 4 | 22 | 22 | 4 |
| -60 | 35 | 13 | 6 | 18 | 27 | 6 |
| -90 | 29 | 22 | 7 | 6 | 31 | 10 |
| | | BULK DENSITY OF THE SOIL FRACTION | | | | |
| | | Grams per cubic centimeter | | | Grams per cubic centimeter | |
| -15 | 35 | 0.67 | 0.06 | 22 | 0.89 | 0.09 |
| -30 | 35 | .66 | .07 | 17 | .94 | .13 |
| -60 | 33 | .81 | .19 | 7 | 1.16 | .11 |
| -90 | 21 | 1.08 | .17 | 0 | -- | -- |
| | | TOTAL COARSE FRAGMENT CONTENT | | | | |
| | | Percent by volume | | | Percent by volume | |
| -15 | 35 | 3 | 2 | 22 | 24 | 11 |
| -30 | 35 | 4 | 7 | 22 | 36 | 17 |
| -60 | 35 | 17 | 62 | 19 | 54 | 22 |
| -90 | 29 | 29 | 21 | 11 | 65 | 22 |

[1]n is the number of soils sampled, $\bar{X}$ the mean, and s the standard deviation. The smaller er of subsoil samples occurs because coarse fragments or bedrock limited sampling.

Laboratory report[4]--0.71-1.15; and elsewhere by Forsythe and Vazquez (1973)--0.80-0.96 g/cm$^3$, and Martini and Palencia (1975) less than 1.0. Pumice soils of central Oregon also have low bulk densities, ranging from 0.5 to 0.9 (Youngberg and Dyrness 1964). Broadfoot and Burke (1958) found, as we did, that bulk densities frequently increased down the profile; however, they report a range in densities of loam and silt loam soils between 1.20 and 1.39 g/cm$^3$.

Coarse fragment percentages (by volume) increased from the surface to lower sampling depths, but the percentages were higher and increased more in basalt soils than in ash soils (table 2). Variability also increased with depth in both groups, notably at 30-60 cm in ash soils. The latter occurred because of the irregular depth of occurrence of the buried soil which contained more coarse fragments.

Mean total soil depth was similar when measured in the soil pit and by screw auger but was lower when measured with the bucket auger (table 3). Soil pits with soil descriptions yield more total information than augers do, however, several augerings can reveal more about depth variability than a single pit excavation can.

[4]Lincoln Soil Survey Laboratory Report for Soils Sampled in Union County, Oregon, 1960. Laboratory Staff, Soil Survey Laboratory, Soil Conservation Service, J.S. Department of Agriculture, Lincoln, Nebr. 1966. Unpublished report, 48 p.

Table 3--*Means and standard deviations of total depth of ash and basalt soils measured by 3 methods*

| Measuring method | Ash soils[1] | | | Basalt soils[1] | | |
|---|---|---|---|---|---|---|
| | n | $\bar{X}$ | s | n | $\bar{X}$ | s |
| | | - Centimeters - | | | - Centimeters - | |
| Soil pit | 35 | 87 | 25 | 22 | 62 | 29 |
| Screw auger | 35 | 91 | 25 | 22 | 57 | 29 |
| Bucket Auger | 35 | 75 | 16 | 22 | 48 | 24 |

[1]n is the number of observations, $\bar{X}$ the mean, and s the standard deviation of total depth.

The ash layer averaged 50 cm thick and had a standard deviation of 11 for 35 sampling sites.

Relationships of moisture content to moisture stress, for particles less than 2 mm, differed between ash and basalt soils (table 4). Moisture content of ash soils was higher at 0.1-bar stress and decreased more rapidly to 1-bar stress than in basalt soils. But, from 1- to 15-bar stress, the rate of change in moisture content was similar in both soil groups although the basalt soils were generally higher in moisture content. Data for the 60- to 90-cm increment of ash soils were associated with the buried layers and were similar to that of basalt soils. Moisture content differences in table 4 also reflect these similarities and show that water yield was greater between 0.1- and 1-bar stress in ash soils but was nearly identical among all soils and depths between 1- and 15-bar stress.

Table 4--*Means and standard deviations of moisture content or content differences by volume at 3 moisture stress levels and two moisture stress ranges for ash and basalt soils (soil fraction only)*

| Sampling interval | n[1] | Moisture stress level and range[2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.1 bar | | 1 bar | | 15 bar | | 0.1 to 1 bar | | 1 to 15 bar | |
| | | $\bar{X}$ | s | $\bar{X}$ | s | $\bar{X}$ | s | $\bar{X}$ | s | $\bar{X}$ | s |
| Centimeters | | - - - - - - - - - - - - - - - - - Percent by volume - - - - - - - - - - - - - - - - - | | | | | | | | | |
| Ash soils: | | | | | | | | | | | |
| 0-15 | 35 | 44.7 | 4.4 | 18.6 | 3.7 | 14.2 | 3.2 | 26.1 | 5.2 | 4.4 | 1.9 |
| 15-30 | 35 | 44.5 | 5.3 | 17.5 | 4.5 | 12.7 | 3.2 | 26.9 | 5.3 | 4.9 | 2.2 |
| 30-60 | 33 | 43.8 | 5.2 | 19.0 | 4.1 | 13.4 | 3.2 | 24.7 | 7.0 | 5.7 | 2.0 |
| 60-90 | 21 | 39.2 | 5.2 | 26.4 | 7.2 | 20.2 | 6.9 | 11.8 | 7.0 | 6.2 | 1.7 |
| Basalt soils: | | | | | | | | | | | |
| 0-15 | 22 | 35.6 | 2.5 | 23.6 | 3.1 | 18.5 | 3.0 | 11.7 | 3.2 | 5.1 | 1.9 |
| 15-30 | 17 | 33.6 | 3.1 | 22.2 | 4.1 | 16.9 | 3.4 | 11.2 | 3.9 | 5.2 | 1.7 |
| 30-60[3] | 7 | 40.3 | 6.2 | 30.3 | 10.0 | 25.1 | 10.0 | 9.9 | 5.4 | 5.0 | 1.3 |

[1]n is the number of observations.

[2]$\bar{X}$ is the mean, and s is the standard deviation of total depth.

[3]No core samples were obtained below this depth in basalt soils.

Moisture content to moisture stress relationships have been generalized in figure 2 to contrast the basalt-derived materials, whether in basalt soil profiles or in buried portions of ash profiles, with the ash-derived mantle of ash profiles. The curves are approximations which serve to illustrate the overlapping nature of these water relations.

Differences in the potential water storage of soil profiles are evident when data are grouped by timber type (fig. 3). An arbitrary soil depth limit of 90 cm was used with stress limits of 0.1 and 15 bars; calculations include the influences of coarse fragments and depth limitations. SF averaged the highest in storage potential and PP the lowest. Limited depth is more of a factor in the PP data since this group was mostly composed of basalt-derived soils which were shallower than ash-derived soils. The term "potential" is used since these values assume recharge of the profile from winter and spring precipitation. This is highly probable in most years.

Other data available for similar Oregon soils were reported for 0.33- and 15-bar stress. Comparisons show strong similarities to the data reported here. Volume percentages were slightly lower than mean values at 15 bars for some buried soils under ash- and surface basalt-derived materials (see footnotes 3 and 4, p. 4 and 5). Simonson and Shearer (1971) reported that mean available water storage data were unusually high (0.24-0.35 inch per inch of soil) in Tolo soils; they attributed this to the presence of volcanic ash. Data herein support their conclusion. Further, their data show a weighted mean available profile storage of 0.31 inch per inch of soil (0.31 cm/cm), which yields 28 cm of available water in 90 cm of soil and compares favorably with SF data in figure 3. There was no indication that adjustments for coarse fragments in the profile were made in their calculations.

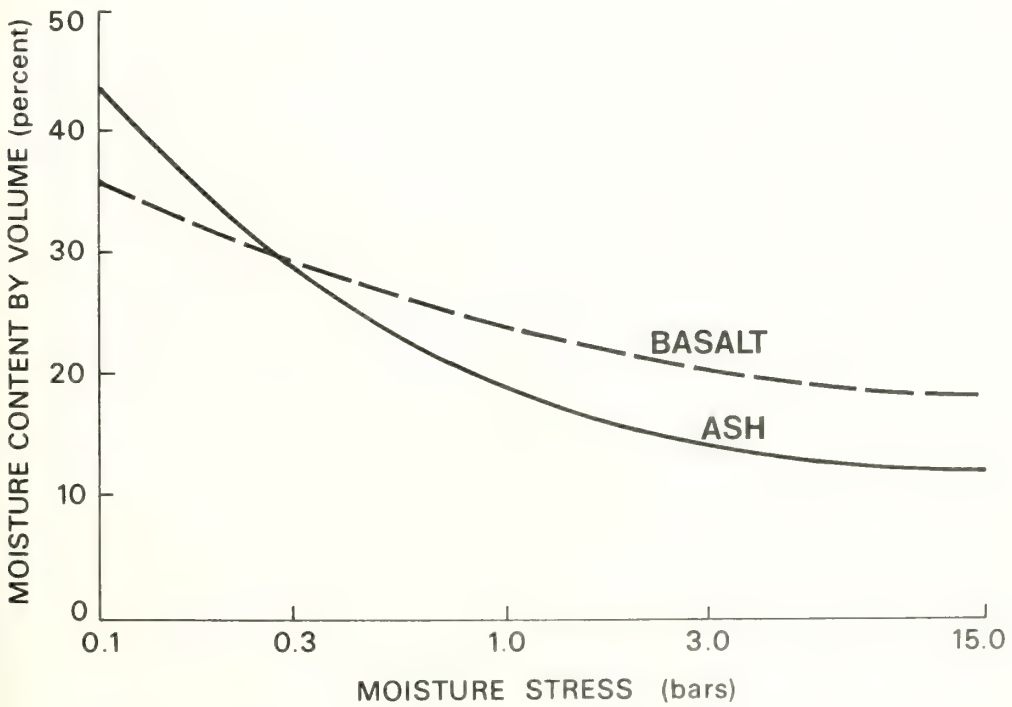


*Figure 2.--Generalized soil moisture content and soil moisture stress relationships in volcanic ash[1] and basalt-derived materials (soil fraction only).*

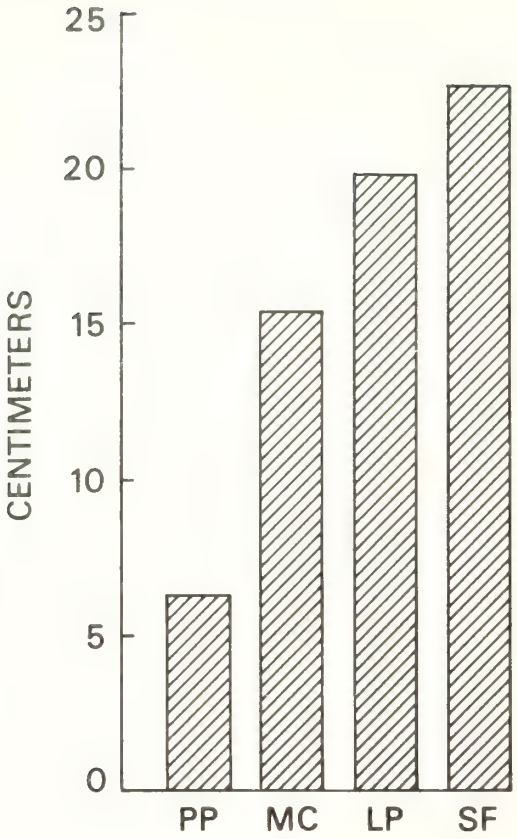


*Figure 3.--Centimeters of potential water storage to a depth of 90 cm in the 0.1- to 15-bar moisture stress range for overstory groupings of soils. PP = ponderosa pine, MC = mixed conifer, LP = lodgepole pine, and SF = spruce-fir.*

## *CHEMICAL PROPERTIES*

Chemical data are presented as concentrations and amounts per unit area. Concentrations (percent or milliequivalents per 100 g) allow contrasts on a unit weight of the 2 mm and finer fraction only, whereas amounts per unit area reflect all measured soil features (depth, bulk density, etc.)

Concentration data for the PP, LP, and MC groups (tables 5, 6, and 7) include those reported by Geist (1974). The pooled data differed little from earlier values. For this reason, commentary will emphasize data expressed in amounts and will contrast them with concentration expressions. Concentration data paralleled the results included in the Lincoln Laboratory report (see footnote 4, p. 5) for similar soils.

The chemical properties of the A1 horizons of several central Oregon pumice soils studied by Youngberg and Dyrness (1964) were contrasted with our 0- to 15-cm intervals. Their values (milliequivalents per 100 g) were mostly lower in K and P by 50 percent or more, were much lower in Mg, were similar or lower in Ca, but were higher in percentages of organic matter and total nitrogen.

Concentration data for the SF group (table 8) show high levels of total N and organic matter, moderate P, and low extractable cations compared with the other overstory groups. Soil reaction (pH) was comparatively low and reflected the lower cation values. Ratios of C:N and Ca:Mg were similar for SF and other groups.

To avoid duplication of published narrative about concentration data in the PP, LP, and MC groups, we direct the reader to discussions of these groups in Geist (1974).

Martini and Palencia (1975) reported chemical properties of Central American ash soils which frequently agree with data for Blue Mountain ash. They noted good agreement with ash soils of South America, Hawaii, and Japan. Specific departures from data reported here included consistently lower concentrations of available P in their soils, whereas organic matter and total N were frequently higher. The authors reported that phosphorus was the most limiting nutrient and that nitrogen was always limiting in greenhouse studies because of slow mineralization. They drew no analogies to native vegetation influences. Morphologically, their soil

| Soil depth | Number of observations | pH ($CaCl_2$) | Organic matter | Total nitrogen | C:N | Available P | Extractable cations | | | | | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | K | Na | Ca | Mg | Total | |
| cm | | - - - - Percent - - - - - | | | | ppm | - - - - - - Milliequivalents per 100 grams - - - - - - | | | | | |
| | | Means[1] | | | | | | | | | | |
| 0-15 | 19 | 5.4 ± 0.1 | 4.08 ± 0.55 | 0.11 ± 0.01 | 22 ± 1 | 44 ± 6 | 1.4 ± 0.2 | 0.1 ± 0.0 | 10.7 ± 0.8 | 2.6 ± 0.4 | 14.8 ± 1.0 | 5 ± 1 |
| 15-30 | 19 | 5.5 ± .1 | 2.16 ± .40 | .07 ± .01 | 19 ± 2 | 31 ± 6 | 1.1 ± .1 | .1 ± 0 | 9.9 ± .8 | 3.0 ± .4 | 14.2 ± 1.0 | 3 ± 0 |
| 30-60 | 15 | 5.5 ± .1 | 1.22 ± .22 | .04 ± .00 | 16 ± 2 | 24 ± 5 | .9 ± .1 | .2 ± 0 | 11.1 ± 1.9 | 4.5 ± .8 | 16.7 ± 2.6 | 3 ± 0 |
| 60-90 | 5 | 5.6 ± .2 | .80 ± .34 | .03 ± .01 | 14 ± 4 | 17 ± 9 | .8 ± .3 | .2 ± .1 | 15.4 ± 6.3 | 7.8 ± 3.2 | 24.3 ± 9.5 | 2 ± 1 |
| | | Ranges | | | | | | | | | | |
| 0-15 | 19 | 5.0-5.8 | 2.28-6.83 | 0.07-0.17 | 19-24 | 26-68 | 0.7-1.9 | 0.1-0.1 | 8.3-14.0 | 1.2-3.9 | 12.1-19.3 | 3-7 |
| 15-30 | 19 | 5.2-5.7 | 1.28-4.26 | .05- .10 | 13-32 | 17-68 | .5-1.6 | .1- .2 | 7.6-12.7 | 1.6-4.4 | 10.9-17.8 | 2-5 |
| 30-60 | 15 | 4.9-5.8 | .66-2.29 | .03- .06 | 11-26 | 15-42 | .6-1.4 | .1- .2 | 7.0-17.1 | 2.1-6.7 | 10.1-24.4 | 2-3 |
| 60-90 | 5 | 5.5-5.8 | .47-1.23 | .02- .04 | 11-20 | 7-25 | .5-1.1 | .1- .3 | 8.8-22.1 | 3.6-10.7 | 13.7-34.0 | 2-3 |
| | | Coefficients of variation (percent) | | | | | | | | | | |
| 0-15 | 19 | 4 | 28 | 25 | 7 | 28 | 26 | 0 | 16 | 30 | 15 | 30 |
| 15-30 | 19 | 2 | 39 | 24 | 24 | 40 | 28 | 35 | 17 | 26 | 15 | 20 |
| 30-60 | 15 | 4 | 32 | 14 | 25 | 37 | 25 | 32 | 31 | 32 | 28 | 17 |
| 60-90 | 5 | 2 | 34 | 21 | 25 | 42 | 30 | 37 | 34 | 34 | 32 | 22 |

[1] ± 95-percent confidence interval.

Table 6--*Chemical properties of soils in the lodgepole pine group*

| Soil depth | Number of observations | pH ($CaCl_2$) | Organic matter | Total nitrogen | C:N | Available P | Extractable cations | | | | | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | K | Na | Ca | Mg | Total | |
| cm | | - - - - Percent - - - - - | | | | ppm | - - - - - - Milliequivalents per 100 grams - - - - - - | | | | | |
| | | Means[1] | | | | | | | | | | |
| 0-15 | 11 | 5.2 ± 0.1 | 3.60 ± 0.55 | 0.09 ± 0.01 | 24 ± 2 | 51 ± 9 | 0.7 ± 0.1 | 0.1 ± 0 | 4.2 ± 0.7 | 1.1 ± 0.1 | 6.0 ± 0.8 | 4 ± 1 |
| 15-30 | 11 | 5.5 ± .1 | 1.60 ± .17 | .05 ± .01 | 18 ± 1 | 31 ± 6 | .7 ± .1 | .1 ± 0 | 4.3 ± 1.0 | 1.1 ± .4 | 6.2 ± 1.3 | 5 ± 1 |
| 30-60 | 11 | 5.6 ± .1 | .88 ± .08 | .03 ± .00 | 16 ± 2 | 17 ± 5 | .8 ± .1 | .2 ± .1 | 6.7 ± 2.0 | 1.9 ± 1.5 | 9.5 ± 3.5 | 5 ± 1 |
| 60-90 | 11 | 5.7 ± .3 | .59 ± .10 | .03 ± .00 | 13 ± 2 | 12 ± 4 | .8 ± .1 | .2 ± .1 | 10.8 ± 3.4 | 3.6 ± 1.9 | 15.4 ± 5.4 | 3 ± 1 |
| | | Ranges | | | | | | | | | | |
| 0-15 | 11 | 4.9-5.5 | 2.29-5.00 | 0.06-0.11 | 20-32 | 33-70 | 0.6-1.0 | 0.1-0.1 | 1.7-5.8 | 0.9-1.4 | 3.3-8.0 | 2-5 |
| 15-30 | 11 | 5.3-5.7 | 1.17-2.11 | .04- .07 | 14-21 | 18-48 | .5-1.0 | .1- .2 | 1.7-7.5 | .6-2.7 | 3.3-11.0 | 2-6 |
| 30-60 | 11 | 5.2-5.8 | .69-1.10 | .03- .04 | 12-20 | 5-27 | .5-1.1 | .1- .4 | 4.0-14.8 | .6-8.7 | 5.6-24.6 | 2-7 |
| 60-90 | 11 | 5.1-6.6 | .39- .86 | .02- .04 | 9-16 | 3-26 | .6-1.0 | .1- .7 | 5.4-25.0 | 1.4-12.0 | 8.7-38.7 | 2-7 |
| | | Coefficients of variation (percent) | | | | | | | | | | |
| 0-15 | 11 | 3 | 23 | 16 | 14 | 26 | 17 | 0 | 25 | 16 | 20 | 21 |
| 15-30 | 11 | 2 | 16 | 15 | 10 | 30 | 22 | 30 | 33 | 52 | 32 | 29 |
| 30-60 | 11 | 3 | 14 | 10 | 17 | 40 | 21 | 52 | 44 | 121 | 55 | 32 |
| 60-90 | 11 | 7 | 25 | 17 | 19 | 46 | 19 | 64 | 46 | 81 | 52 | 41 |

[1] ± 95-percent confidence interval.

Table 7--*Chemical properties of soils in the mixed conifer group*

| Soil depth | Number of observations | pH ($CaCl_2$) | Organic matter | Total nitrogen | C:N | Available P | Extractable cations | | | | | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | K | Na | Ca | Mg | Total | |
| cm | | - - - - - Percent - - - - - | | | | ppm | - - - - - - Milliequivalents per 100 grams - - - - - - | | | | | |
| | | Means[1] | | | | | | | | | | |
| 0-15 | 20 | 5.6 ± 0.1 | 3.43 ± 0.46 | 0.10 ± 0.01 | 20 ± 1 | 63 ± 12 | 1.4 ± 0.2 | 0.1 ± 0 | 8.2 ± 1.5 | 1.5 ± 0.3 | 11.2 ± 2.0 | 6 ± 1 |
| 15-30 | 20 | 5.5 ± .1 | 1.93 ± .29 | .06 ± .01 | 18 ± 1 | 36 ± 9 | 1.1 ± .1 | .1 ± 0 | 6.8 ± 1.6 | 1.3 ± .3 | 9.3 ± 2.0 | 5 ± 1 |
| 30-60 | 20 | 5.4 ± .1 | 1.37 ± .27 | .04 ± .01 | 18 ± 2 | 22 ± 6 | 1.0 ± .1 | .2 ± 0 | 8.0 ± 1.5 | 2.1 ± .4 | 11.2 ± 2.0 | 4 ± 1 |
| 60-90 | 12 | 5.3 ± .2 | .61 ± .06 | .03 ± 0 | 12 ± 1 | 12 ± 3 | .8 ± .1 | .3 ± 0 | 9.9 ± 0.8 | 3.8 ± .4 | 14.8 ± 1.1 | 3 ± 0 |
| | | Ranges | | | | | | | | | | |
| 0-15 | 20 | 5.2-5.9 | 1.73-5.43 | 0.06-0.16 | 17-25 | 22-111 | 0.8-2.2 | 0.1-0.1 | 4.6-15.7 | 0.9-3.2 | 6.5-21.1 | 4-10 |
| 15-30 | 20 | 5.1-5.8 | 1.14-3.48 | .04- .11 | 13-21 | 11- 76 | .5-1.6 | .1- .2 | 2.3-14.8 | .6-2.6 | 3.5-18.6 | 4-9 |
| 30-60 | 20 | 4.7-5.7 | .79-3.23 | .03- .10 | 13-33 | 8- 47 | .5-1.6 | .1- .3 | 4.0-14.4 | 1.1-4.7 | 6.3-20.0 | 2-7 |
| 60-90 | 12 | 4.7-5.7 | .44- .75 | .03- .04 | 9-16 | 6- 21 | .6-1.1 | .2- .4 | 8.5-11.6 | 2.7-5.1 | 12.0-17.7 | 2-4 |
| | | Coefficients of variation (percent) | | | | | | | | | | |
| 0-15 | 20 | 3 | 29 | 28 | 10 | 39 | 29 | 0 | 40 | 49 | 38 | 27 |
| 15-30 | 20 | 3 | 32 | 31 | 13 | 55 | 26 | 22 | 52 | 49 | 46 | 31 |
| 30-60 | 20 | 4 | 43 | 38 | 26 | 56 | 25 | 36 | 41 | 43 | 38 | 30 |
| 60-90 | 12 | 7 | 16 | 14 | 18 | 42 | 16 | 26 | 12 | 18 | 11 | 19 |

[1] ± 95-percent confidence interval.

Table 8--*Chemical properties of soils in the spruce fir group*

| Soil depth | Number of observations | pH ($CaCl_2$) | Organic matter | Total nitrogen | C:N | Available P | Extractable cations | | | | | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | K | Na | Ca | Mg | Total | |
| cm | | - - - - - Percent - - - - - | | | | ppm | - - - - - - Milliequivalents per 100 grams - - - - - - | | | | | |
| | | Means[1] | | | | | | | | | | |
| 0-15 | 7 | 4.8 ± 0.3 | 7.89 ± 2.71 | 0.22 ± 0.07 | 21 ± 2 | 45 ± 21 | 0.6 ± 0.2 | 0.1 ± 0.0 | 3.0 ± 1.8 | 0.8 ± 0.3 | 4.4 ± 2.1 | 4 ± 2 |
| 15-30 | 7 | 5.0 ± .2 | 4.70 ± 1.61 | .16 ± .07 | 18 ± 3 | 21 ± 10 | .5 ± .3 | .1 ± 0 | 1.8 ± 1.5 | .6 ± .3 | 3.0 ± 1.9 | 3 ± 2 |
| 30-60 | 7 | 5.0 ± .1 | 2.34 ± 1.06 | .09 ± .04 | 14 ± 1 | 17 ± 7 | .4 ± .3 | .1 ± 0 | 1.6 ± 1.0 | .6 ± .2 | 2.7 ± 1.4 | 2 ± 1 |
| 60-90 | 7 | 4.7 ± .3 | 1.02 ± 0.36 | .06 ± .02 | 10 ± 1 | 26 ± 11 | .6 ± .2 | .1 ± 0 | 6.1 ± 2.7 | 2.0 ± .8 | 8.8 ± 3.5 | 3 ± 1 |
| | | Ranges | | | | | | | | | | |
| 0-15 | 7 | 4.5-5.3 | 4.98-13.36 | 0.14-0.36 | 17-24 | 13-80 | 0.4-1.1 | 0.0-0.1 | 0.7-5.5 | 0.2-1.0 | 1.8-7.5 | 1-7 |
| 15-30 | 7 | 4.7-5.3 | 2.48-8.00 | .07- .29 | 15-23 | 10-42 | .3-1.1 | 0.0- .1 | .3-4.2 | .2- .9 | .9-5.9 | 1-5 |
| 30-60 | 7 | 4.8-5.3 | .99-4.18 | .05- .16 | 12-17 | 10-29 | .2-1.0 | .1- .1 | .3-3.5 | .2- .9 | .8-4.9 | 1-4 |
| 60-90 | 7 | 4.3-5.2 | .60-1.65 | .04- .08 | 8-12 | 12-46 | .4- .9 | .1- .2 | 2.4-9.9 | 1.0-3.5 | 3.9-14.1 | 2-4 |
| | | Coefficients of variation (percent) | | | | | | | | | | |
| 0-15 | 7 | 6 | 37 | 36 | 11 | 51 | 45 | 44 | 64 | 36 | 51 | 54 |
| 15-30 | 7 | 4 | 37 | 46 | 16 | 51 | 60 | 44 | 90 | 46 | 67 | 58 |
| 30-60 | 7 | 3 | 49 | 49 | 11 | 44 | 64 | 0 | 71 | 42 | 57 | 40 |

[illegible] 95-percent confidence interval.

have much deeper ash layers with thick (50+-cm), dark, A horizons. They sampled by horizon rather than fixed depths which partially accounts for differences in some chemical properties.

The appearance and hence interpretation of results can be affected by method of expression. Little difference in relationships among group means is seen when concentrations of organic matter are compared with amounts per unit area (fig. 4A versus 4B). But there are notable differences among group means when concentrations of Ca+Mg+K at depth increment 4 are compared with amounts at 90 cm (fig. 5A versus 5B). This is due to interacting effects contributed by coarse fragment percentages, bulk densities, total depth, and texture of the soils. Calcium and magnesium dominated the extractable cations, and both closely followed the trends shown for the summed cations.

This clouded the dynamics of potassium values, so they have been separated and reported with the nitrogen and phosphorus data (table 9). A decline and rise progressing from the first through the third sampling interval (partially due to sampling interval thickness) occurred in all properties except for total N and available P in the PP group. Amounts of N further declined in the fourth increment for all groups; P and K also declined in all but the SF

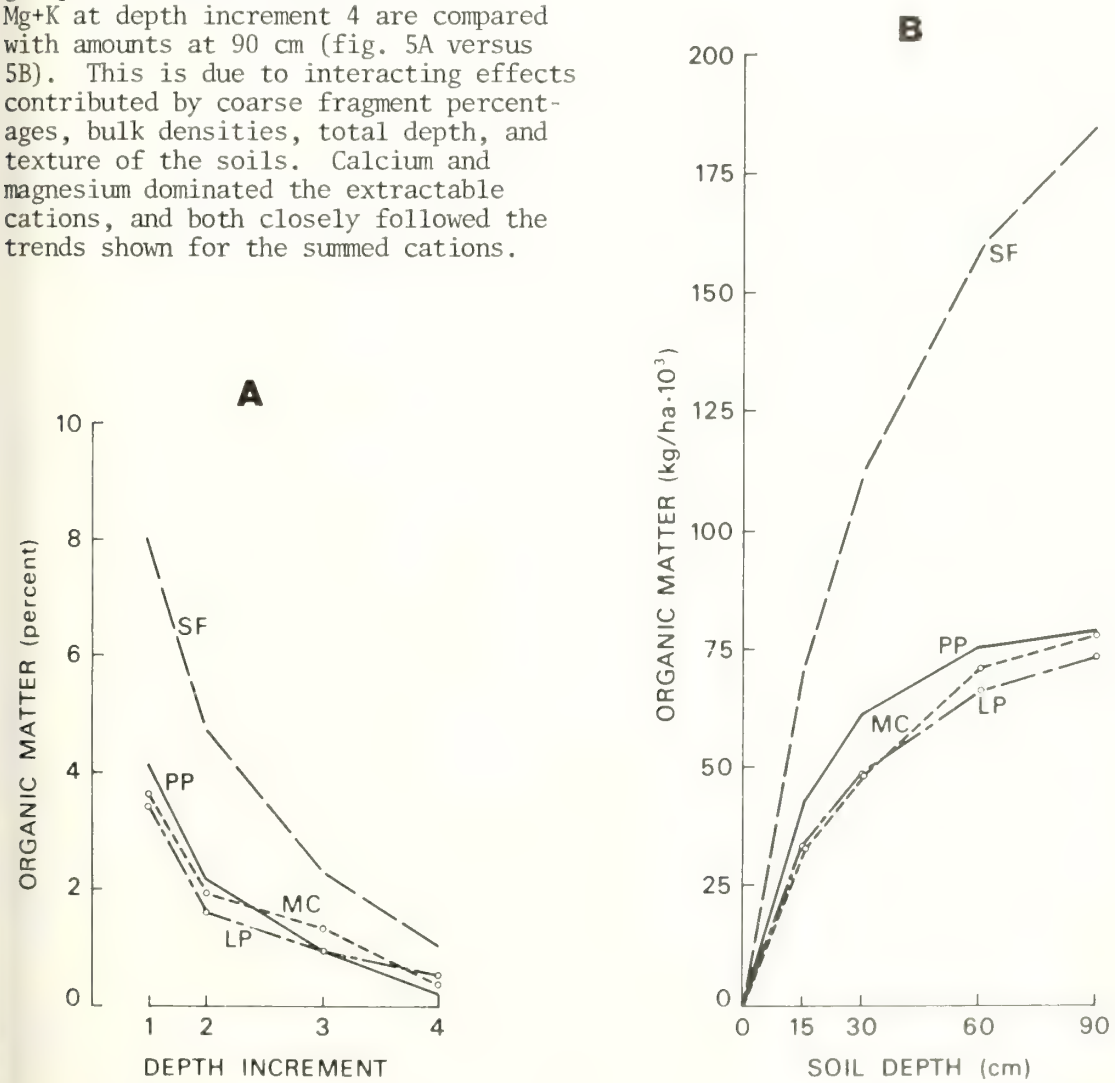


*Figure 4.--Mean percentages (A) and cumulative amounts (B) of organic matter by overstory groups. PP = ponderosa pine; MC = mixed conifer; LP = lodgepole pine; and SF = spruce-fir.*

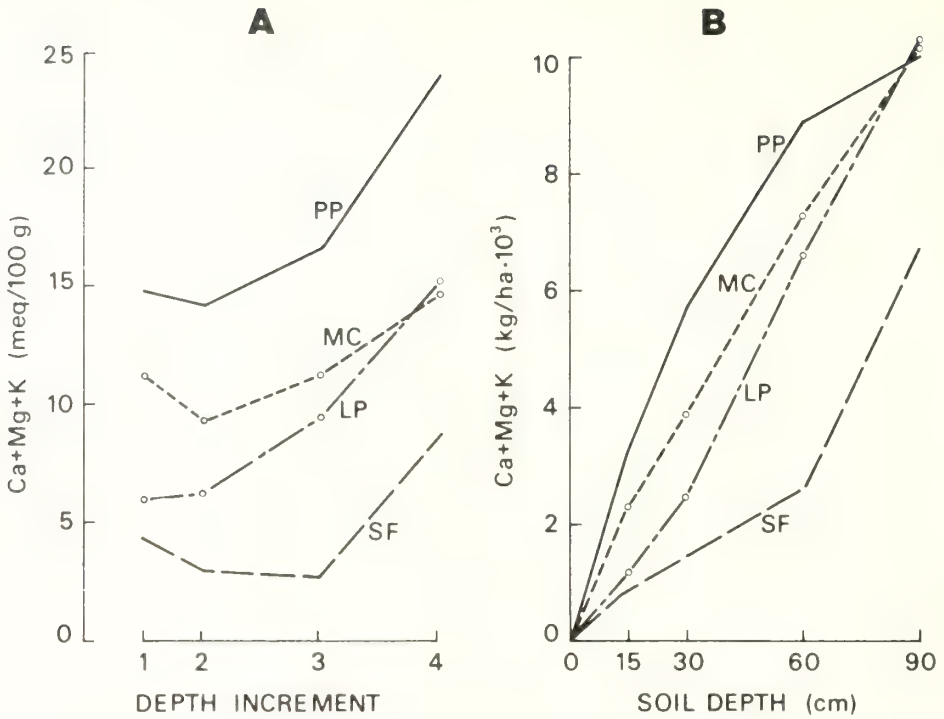


*Figure 5.--Mean extractable cation contents (A) and cumulative amounts of cations (B) by overstory groups. PP = ponderosa pine; MC = mixed conifer; LP = lodgepole pine; and SF = spruce-fir.*

group where amounts increased. Although not shown in table 9, the decline and increase and decline trends were followed by summed cations and organic matter, except that summed cations in the 60-90 interval rose sharply in the SF group and slightly in the LP. Means for cumulative total N were similar in all but the SF group, which was much higher. The SF group was highest in total available P (although strongly subsoil distributed) but lowest in total extractable K. The MC group had the highest total extractable K and was near the high in total available P. Lowest total available P occurred in the PP group.

Cole et al. (1967) reported values of 2 809, 3 878, and 234 kg/ha for total N, extractable P, and extractable K in 60 cm mineral soil derived from glacial outwash in the Puget Sound Basin. Their soil supported a 36-year-old stand of second-growth Douglas-fir. Compared with data in table 9, the glacial soil was higher in P, lower in extractable K, and higher in N except for the SF group.

In comparisons of soils supporting 30-year-old stands of red alder-Douglas-fir with only Douglas-fir in southwestern Washington, Tarrant and Miller (1963) found 4 225 and 3 174 kg of total N per hectare, respectively. These values were for the total of forest floor and mineral soils to 91 cm from sites having a history of at least three fires. The values were higher than in our study soils under mature stands of PP, LP, and MC.

Williams and Dyrness (1967) sampled soils in the Cascade Range under true fir and hemlock stands. Their data, reported by geographic provinces, showed mean values ranging from 5 077 to 13 456 kg of total N

Table 9--*Mean amounts of nitrogen (N), phosphorus (P), and potassium (K) in overstory groups by sampling interval and summed to 90-cm depth*

| Group and sampling increment | Observations | Total N[1/] | | Available P[1/] | | Extractable K[1/] | |
|---|---|---|---|---|---|---|---|
| | | $\bar{X}$ | s | $\bar{X}$ | s | $\bar{X}$ | s |
| Centimeters | | Kilograms per hectare | | | | | |
| Ponderosa pine: | | | | | | | |
| 0-15 | 19 | 1 151 | 245 | 47 | 16 | 608 | 204 |
| 15-30 | 19 | 588 | 112 | 29 | 14 | 404 | 168 |
| 30-60 | 17 | 553 | 372 | 29 | 25 | 446 | 359 |
| 60-90 | 9 | 234 | 241 | 12 | 14 | 244 | 303 |
| Total (0-90)[2/] | 19 | 2 345 | -- | 108 | -- | 1 527 | -- |
| Lodgepole pine: | | | | | | | |
| 0-15 | 11 | 830 | 162 | 48 | 13 | 273 | 44 |
| 15-30 | 11 | 494 | 69 | 30 | 9 | 266 | 67 |
| 30-60 | 11 | 649 | 258 | 32 | 14 | 596 | 219 |
| 60-90 | 10 | 339 | 298 | 13 | 12 | 420 | 358 |
| Total (0-90)[2/] | 11 | 2 281 | -- | 122 | -- | 1 517 | -- |
| Mixed conifer: | | | | | | | |
| 0-15 | 20 | 935 | 251 | 62 | 29 | 520 | 149 |
| 15-30 | 20 | 532 | 177 | 33 | 22 | 376 | 137 |
| 30-60 | 20 | 690 | 346 | 37 | 30 | 625 | 322 |
| 60-90 | 17 | 400 | 321 | 18 | 20 | 409 | 335 |
| Total (0-90)[2/] | 20 | 2 497 | -- | 147 | -- | 1 869 | -- |
| Spruce fir: | | | | | | | |
| 0-15 | 7 | 1 970 | 624 | 41 | 21 | 229 | 111 |
| 15-30 | 7 | 1 410 | 585 | 19 | 10 | 184 | 110 |
| 30-60 | 7 | 1 883 | 913 | 34 | 14 | 342 | 196 |
| 60-90 | 7 | 1 445 | 548 | 63 | 28 | 571 | 143 |
| Total (0-90)[2/] | 7 | 6 708 | -- | 157 | -- | 1 326 | -- |

[1/] $\bar{X}$ is the mean and s the standard deviation.

[2/] The reason for the disparity between 0- to 90-cm means and totals of interval means is that zero values associated with locations lacking soil in the 30- to 60- or 60- to 90-cm increments were included in the 0- to 90-cm mean but were not included in interval means.

per hectare, 22 to 56 kg of available P per hectare, 283 to 1 167 kg of extractable K per hectare for soil depths extending to bedrock or stony layers but excluding the forest floor. Thus, their soils were higher in total N and lower in extractable P and K than ours.

The amount of total N (1 981 kg/ha) in 61 cm of a typical central Oregon soil of pumice origin (Youngberg and Dyrness 1964) was similar to means in all but the SF group. Available P (31 kg/ha) was about two-thirds and extractable K (614 kg/ha) about half the mean levels reported in this paper, except that extractable K in the SF group exceeded that of the pumice soil by only 140 kg/ha. Youngberg and Dyrness commented that 61 cm of soil in western Oregon on a medium site supporting Douglas-fir contains 8 960 kg/ha of total N, and other nutrients are correspondingly higher.

## Discussion

The weaker structural development and larger percentage of silt-size

particles in surface layers of ash soils indicate a higher topsoil erosion potential than for basalt-derived materials. In our study area, precipitation principally occurs as winter snow and gentle spring rain; thunderstorms are comparatively infrequent. Thus, neither material is highly vulnerable under natural cover conditions, but, with disturbance, both soils readily erode. Channeling of surface runoff leads to varying degrees of rill and gully formation. A rather unique property of ash layers reduces their susceptibility to water erosion. Until soil pores are saturated, soil particles tend to lock together like a jigsaw puzzle. It is common to see undisturbed walls of soil pits, several years old, showing very minor side sloughing. Under dry conditions, the exposed and disturbed ash layer is highly susceptible to wind erosion.

A patchy and variable degree of water repellency was noted in several ash profiles. This has been observed in ash soils elsewhere (Martini and Palencia 1975) but is not unique to ash soils. Some workers think that the degree of repellency, at times, is positively correlated with dryness in the field prior to rewetting.

Surface runoff from the basalt-derived soils under natural conditions is moderate because of limited depth and moderate infiltration and internal drainage, whereas runoff from ash soils is lower because of higher infiltration rates and rapid internal drainage in the ash overburden. Buried basalt-derived materials retard internal drainage to a degree depending on their textural and structural properties. Surface runoff from either soil will usually increase with surface disturbance.

Observations of roadside cuts indicate that the most frequent slumping of ash soils occurs when finer textured buried layers become water saturated and cannot support the ash materials above. This occurs even though the moisture percentage of the ash may b as high or higher than lower materia When internal water movement during the wetting process is retarded at the ash-buried soil interface or at bedrock, a lubricated contact plane results and creates a condition conducive to soil slippage. The hazard for both slumps and slippage increas as the slope gradient increases.

The uniformity of surface bulk density, particularly in volcanic as soils, has practical application sin it offers a fairly stable benchmark for assessing soil compaction. But displacement of the surface soil in logging and associated operations in creases the natural variability of t new surface and increases the difficul of measuring compaction. The numbe of samples required to estimate the mean density with the same accuracy is greater after disturbance than before.

Soil bulk densities are commonl assumed to be higher than 1.0 g/cm$^3$. If such an assumption was applied to the surface layer of study soils, it would lead to errors of 30 percent o more. Too, soil scientists frequent assume that an acre-6 inches of soil weighs 2 million pounds. Such an assumption for ash soils can lead to errors of 50 percent since the assum value corresponds to a bulk density 1.47 g/cm$^3$. Broadfoot and Burke's (1958) tables for estimating bulk density give values which are too hi and should not be applied to the stu soils or others with significant ash influence.

An average particle density of 2.65 g/cm$^3$ was assumed for the soil materials studied. Ross (see footno 3, p. 4) found particle densities between 2.49 and 2.75 g/cm$^3$ in north eastern Oregon. Youngberg and Dyrne (1964) reported values that ranged from 2.35 to 2.83 g/cm$^3$, and average 2.61, for pumice in central Oregon. Thus, it appears our assumption was reasonable and did not significantly influence the data presented.

Coarse fragments can strongly influence site productivity and are an important factor to note in inventory efforts. Coarse fragments dilute soil nutrients on a volume basis. When present in the surface soil, they can improve the effectiveness of infrequent growing season precipitation but detract from total water storage capacity. We consider water storage capacity to generally be more important to vegetation growth in the Blue Mountains. Hence, coarse fragments, regardless of profile position, are considered a negative influence on productivity of Blue Mountain soils.

Ash soils store about twice the volume of water that basalt soils store between 0.1- to 15-bar stress. Most of the water stored in ash soils is available to plants in the low stress range (0.1- to 1-bar). Similar relationships were reported for pumice soils (Youngberg and Dyrness 1964, Packard 1957). Thus, plants should experience comparatively little soil moisture stress in ash soils during early periods of growth.

Basalt soils yield water in a fairly linear fashion between the stress extremes measured; however, surface soils with greater ash influence assume a more curvilinear relationship. It becomes important, then, to assess the degree of ash influence when water relations of basalt soils are evaluated.

The effect of the factors discussed above was best illustrated by the comparisons of water storage capacity by overstory group (fig. 3). The strong association of ponderosa pine for low moisture sites is evident. Most of these sites were also associated with southern or southwest exposures which adds to their droughty nature.

Water-holding relationships reported by Broadfoot and Burke (1958) for silt loam (medium texture) soils underestimate values found here for volcanic ash materials. Thus, as noted for bulk densities, serious errors can result from applying their data to water storage computations in our study soils.

High values for organic matter and total N are strongly associated with the SF group. Spruce-fir stands usually occur on deep soils at higher elevation and precipitation zones, and they visibly appear more productive than the other three groups. Thus, the vegetative and environmental factors are confounded and potential cause-effect relationships cannot be drawn. Low values for total cations and pH suggest that higher precipitation is providing more profile leaching and/or lower base cycling occurs in SF vegetation than in other soils and vegetation.

In all overstory groups, organic matter percentages decline about 50 percent for each step down in sampling interval. About two-thirds of the total organic matter and nitrogen present in the upper 90 cm of soil of PP, MC, and LP groups occurs in the top 30 cm. The distribution is less skewed in the SF group where about half the organic matter and total nitrogen occurs in the upper 30 cm. Hence, the top 30 cm (1 foot) of soil contains a disproportionately large nutrient reservoir. Since nitrogen is always implicated in nutrient deficiencies of soils in the Blue Mountains (Geist 1976), this quantification lends support to the adage: "Protect your topsoil." Phosphorus, too, is most often highest in the surface layers although some buried soil layers contain fairly high quantities. Again, these results encourage maintenance of topsoil.

The disparities in interpretation between expressions in concentrations and amounts of some chemical properties raise questions about which expression relates most meaningfully to plant nutrition and production. It seems logical that concentrations would be

more important to shallow-rooted plants. If this is true, size and kind of rooting pattern are important factors influencing adaptability of plants to sites. Mature plants with well-developed, deep root systems would be more affected by total amounts of nutrients in the soil.

Debate over concentrations versus amounts may be unnecessary when comparing fertility of soils with similar bulk densities. Since many soils have surface bulk densities over 1.0 $g/cm^3$, however, a sizable error can occur when these soils are contrasted with soils of low densities. This point was stressed by Youngberg and Dyrness (1964) who preferred expressions of amount per unit area. The dilution effect of low bulk density is chemically similar to the effect of a high content of coarse fragments but is physically dissimilar because low bulk density is accompanied by high porosity. The latter factor is one reason why moisture percentage on a volume basis is favored over a weight basis (Packard 1957).

The above disparity also raises questions about how soils should be sampled for greenhouse growth experiments. Should one include coarse fragments? Should soil comparisons be made on an equal weight basis or equal volume basis? The answers are partially dependent on objectives; either approach alone may be unsatisfactory. Where bulk densities are similar, a fixed weight basis of comparison seems justified. With differing densities, a means of discounting weight differences should be used with equal volumes of potted soil.

Expressing chemical factors on a amount per unit area basis may also b preferred since this allows direct summation of data for sampling intervals. Thus, depth factors are easily changed for studying plant relationships. Allowance for physical influences is also easily made when chemical units are kilograms per hectare.

Sampling depth control is impera tive to collection of representative soils samples in view of sharp gradients in chemical and physical properties down the profile. This is particularly true in cases where repetitive sampling is involved and fixed depths are used.

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# Appendix

The following examples of applications of chemical and physical data apply to both current and future problems of resource managers.

Example 1:

Find the centimeters of plant available water stored in a soil segment between specified soil water stress limits (we have assumed that field capacity and permanent wilting occur at 0.1- and 15-bar stress, respectively):

Centimeters of water storage = water content percentage difference for stress range/100 x soil depth in cm x soil volume percentage;

i.e., for 30 cm ash soil between 0.1 and 15 bars stress with 10 percent coarse fragments:

8.9 cm water = 45-12% by volume/100 x 30 x 100-10%/100.

The 8.9 cm represents about 8.9/30 x 100 or 30 percent of the soil section volume as storage capacity for the *stated stress limits*. This kind of calculation is useful to watershed personnel for figuring water balance relationships. This example can also be used to compute loss of soil moisture caused by erosion or displacement of soil from scalping or slash piling operations.

Example 2:

Find the amount of nutrients in a given soil segment:

Amount of nutrients in kg/ha = meq/g x meq weight in grams x depth in cm x mass of ha-cm water x bulk density x soil volume percentage.

One ha-cm water has a mass of $10^5$ kg; this is similar to the concept for weight of an acre-foot of water. Find kg/ha K in 15 cm of ash surface soil, with a 20-percent volume of coarse fragments with a soil bulk density of 0.7 g/$cm^3$, where the soil contains 1.2 meq K/100 g:

0.012 x 0.0391 x 15 x 100,000 x 0.7 x 0.8 = 394 kg K/ha.

As we learn more about timber or forage nutrient requirements, such calculations will be more important for assessing or ranking the fertility and productivity of management units.

Example 3:

A catchment basin contains 110,000 kg (121.2 tons) of sediment material and is estimated to contain 20 percent ash and 80 percent basalt-derived surface soil with natural bulk densities of 0.7 and 0.9, respectively. The watershed associated with the catchment has an area of 20 ha; however, the actual areas of the sediment sources were 0.1 ha of an ash soil and 0.3 ha of basalt soil. Neither soil contained over 5 percent coarse fragments. The sediment came from sheet erosion which was assumed to be equally distributed over the source areas. (This assumption makes the problem simple but is seldom justified in practice.) Calculate the thickness of soil lost from the two eroding areas:

cm of soil = (sediment mass in kg)(sediment percentage)/(mass of ha-cm of water) (bulk density of native soil) x 1/eroded area in ha.

(Coarse fragments equal to 10 percent or more by volume in the native soil should be accounted for in the calculations, whether they were left behind on the erosion site or were present in the sediment basin. Sizable errors can result if these fragments are ignored.)

For the ash soil:

$$\frac{110{,}000 \times 0.2}{100{,}000 \times 0.7} \times \frac{1}{0.1} = 3.1 \text{ cm thickness.}$$

For the basalt-derived soil:

$$\frac{110{,}000 \times 0.8}{100{,}000 \times 0.9} \times \frac{1}{0.3} = 3.3 \text{ cm thickness.}$$

Analyses of the sediment would allow calculations of the nutrients lost because of erosion. If the eroded area was monitored with graduated stakes, measured readings of soil loss could be compared with calculated values. Frost heaving or other disturbances often make the use of such stakes difficult, but they can be advantageous in some circumstances.

GPO 986-312

Geist, J. Michael, and Gerald S. Strickler.
1978. Physical and chemical properties of some Blue Mountain soils in northeast Oregon. USDA For. Serv. Res. Pap. PNW-236, 19 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Soil properties of 57 forested locations were characterized and categorized by parent materials and vegetation. Properties were compared and interrelated, and their management implications were discussed. Data will serve as a basis for comparison with other soil-vegetation systems and for assessing environmental impacts.

KEYWORDS: Soil properties (physical), soil properties (chemical), soil management, plant-soil relations, volcanic ash soil, Oregon (Blue Mountains).

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USDA FOREST SERVICE RESEARCH PAPER PNW-237
1978

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# PONDEROSA PINE LUMBER RECOVERY -- Young Growth in Northern California

By
Richard O. Woodfin

DOCUMENTS

Pacific Northwest Forest and Range Experiment Station
Forest Service U. S. Department of Agriculture
Portland, Oregon

# *Ponderosa Pine Lumber Recovery—*
# *Young Growth In Northern California*

*Reference Abstract*

Woodfin, Richard O.
1978. Ponderosa pine lumber recovery--young growth in northern California. USDA For. Serv. Res. Pap. PNW-237, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Young-growth ponderosa pine logs from the Shasta-Trinity National Forest yielded 78 percent of volume in No. 3 and 4 Common grade lumber. Cubic recovery information and lumber grade recovery by log diameter classes are presented for the Grade 4 and 5 logs.

KEYWORDS: Lumber grading, lumber recovery, ponderosa pine, *Pinus ponderosa*, young growth, California (northern).

*RESEARCH SUMMARY*

*Research Paper PNW-237*

*1978*

Product yield information available to the forest products industry and timber managers must be periodically re-evaluated to reflect changes in grades, technology, and items produced. No. 3 Common lumber represented 55.4 percent of the product recovery from Grade 5 logs. This was more than double the volume of grade No. 3 Common lumber from old-growth logs.

Cubic recovery is discussed noting the recovery volume relationships between precise manufacture and both board feet lumber tally and cubic feet of lumber produced.

Resource utilization by processing stages is presented for the study log sample. Chippable residue volumes are shown by log size classes. Average cubic lumber recovery was 55 percent.

## Introduction

Product yield information available to the forest products industry and timber managers must be periodically re-evaluated to reflect changes in lumber grades, processing technology, and the mix of lumber items produced. This report presents new information about lumber grade recovery and cubic volume relationships for unpruned young-growth ponderosa pine in northern California. It is based on a study designed to provide product yield that reflects some of these changes. The information is based on 170 ponderosa pine trees in the 60- to 80-year age class selected from the McCloud Ranger District of the Shasta-Trinity National Forest.

Approximately 10.0 MM board feet of ponderosa pine in all age classes are harvested annually from the McCloud District. Most of this volume is from trees above 18-inch diameter at breast height (d.b.h.).

There are several earlier recovery reports on ponderosa pine that are available for comparison to the results presented here (Gaines 1962, Matson 1955, Wise 1964, and Mueller and Kovner 1967).

The sample trees were selected by representatives of the Pacific Northwest Forest and Range Experiment Station; the California Region, U.S. Forest Service; and a northern California forest products company. A selection of trees was made from a timber stand considered representative of the size and quality range of second-growth ponderosa pine currently being harvested in northern California. Individual trees were felled, bucked, and identified by tree and log number. This number identified the lumber items from each log throughout the sawing and planing phases of the study and was the basis for compilation and analysis of log and tree data. Bucked logs were scaled and graded according to U.S. Forest Service scaling handbook rules (USDA Forest Service 1973b). Table 1 summarizes log size and log scale information. Logs were sawn in 8- to 18-foot lengths with most logs being 16 feet long. The processing equipment at this cooperating mill included ring debarker, two band headsaws, edger, trimsaw, and resaw.

### GRADE RECOVERY

Lumber grade recovery by log grade and diameter classes is presented in tables 2 and 3. The volumes of grades produced by board sizes are shown in table 4. The lumber items included 1,338 board feet of 4/4-inch Selects, Moulding, and Shop grades; 5,877 board feet of 5/4-inch items; and 68,389 board feet of 4/4-inch Common grades. These volumes are 1.8, 7.8, and 90.4 percent of the total volume, respectively.

Table 1--*Summary of young-growth ponderosa pine log scale and cubic recovery values*

| Log grade 1/ | Number of logs | Scribner log scale | | Scaled defect | Overrun (recovery) percent | Cubic recovery | Lumber tally | Lumber recovery factor 2/ |
|---|---|---|---|---|---|---|---|---|
| | | Gross | Net | | | | | |
| | | - Board feet - | | - - - - - Percent - - - - - | | | Board feet | |
| 4 | 28 | 2,360 | 2,350 | 0 | 16 | 57 | 2,724 | 6.62 |
| 5 | 675 | 64,400 | 63,670 | 1 | 14 | 55 | 72,880 | 6.46 |
| Total | 703 | 66,760 | 66,020 | 1 | 15 | 55 | 75,604 | 6.46 |

1/ Improved grades for ponderosa pine and sugar pine.

2/ Board feet lumber tally per cubic foot of gross log volume.

Table 2--*Surfaced dry lumber grade recovery by log diameter classes for young-growth ponderosa pine Grade 4 logs*[1/]

| Log scaling diameter | Number of logs | Lumber tally | Lumber grades | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | D and Better Select | Moulding and No. 3 Clear | Shop | | | Common | | | | |
| | | | | | No. 1 | No. 2 | No. 3 | Nos. 1 and 2 | No. 3 | No. 4 | No. 5 | |
| Inches | | Board feet | Percent | | | | | | | | | |
| 8 | 2 | 59 | --[2/] | -- | -- | -- | -- | 37.29 | 49.16 | 8.47 | 5.08 | 100.00 |
| 9 | 1 | 23 | -- | -- | -- | -- | -- | 30.43 | 21.74 | 47.83 | -- | 100.00 |
| 10 | 6 | 382 | -- | -- | -- | -- | -- | 12.04 | 53.41 | 29.84 | 4.71 | 100.00 |
| 11 | 2 | 197 | -- | -- | -- | -- | -- | 45.69 | 42.64 | 10.15 | 1.52 | 100.00 |
| 12 | 6 | 466 | .64 | -- | -- | -- | -- | 20.60 | 66.53 | 10.94 | 1.29 | 100.00 |
| 13 | 3 | 310 | -- | -- | -- | -- | -- | 4.19 | 77.42 | 18.39 | -- | 100.00 |
| 14 | 3 | 393 | -- | -- | -- | -- | -- | 27.23 | 63.87 | 4.07 | 4.83 | 100.00 |
| 15 | 2 | 366 | -- | -- | -- | -- | -- | 12.30 | 74.59 | 11.20 | 1.91 | 100.00 |
| 16 | 2 | 339 | -- | 1.18 | -- | -- | 3.83 | -- | 60.48 | 25.07 | 9.44 | 100.00 |
| 17 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | 1 | 189 | -- | -- | 3.70 | -- | -- | 25.40 | 57.67 | 13.23 | -- | 100.00 |
| Average or total | 28 | 2,724 | .11 | .15 | .25 | -- | .48 | 17.40 | 62.78 | 15.60 | 3.23 | 100.00 |

[1/] Percentages are actual values uncurved.

[2/] -- = No recovery in these lumber grades and diameter classes.

Table 3--*Surfaced dry lumber grade recovery by log diameter classes for young-growth ponderosa pine Grade 5 logs*[1/]

| Log scaling diameter | Number of logs | Lumber tally | Lumber grades | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | D and Better Select | Moulding and No. 3 Clear | Shop | | | Common | | | |
| | | | | | No. 1 | No. 2 | No. 3 | Nos. 1 and 2 | No. 3 | No. 4 | No. 5 | |
| Inches | | Board feet | Percent | | | | | | | | |
| 5 | 21 | 328 | --[2/] | -- | -- | -- | -- | 14.33 | 58.53 | 19.21 | 7.93 | 100.00 |
| 6 | 60 | 1,155 | .52 | -- | -- | -- | -- | 9.35 | 57.92 | 23.29 | 8.92 | 100.00 |
| 7 | 47 | 1,256 | -- | -- | -- | -- | -- | 13.85 | 53.75 | 25.08 | 7.32 | 100.00 |
| 8 | 63 | 1,868 | -- | .21 | -- | -- | -- | 11.83 | 61.73 | 20.45 | 5.78 | 100.00 |
| 9 | 58 | 2,448 | .16 | .37 | -- | -- | -- | 11.19 | 62.75 | 21.24 | 4.29 | 100.00 |
| 10 | 48 | 3,075 | .16 | -- | -- | -- | .10 | 9.63 | 61.04 | 25.69 | 3.38 | 100.00 |
| 11 | 45 | 3,430 | .20 | -- | -- | -- | .50 | 9.65 | 64.37 | 21.81 | 3.47 | 100.00 |
| 12 | 51 | 4,763 | .25 | -- | -- | -- | .17 | 13.00 | 66.32 | 16.42 | 3.84 | 100.00 |
| 13 | 46 | 5,247 | .27 | -- | -- | -- | .51 | 12.29 | 64.42 | 18.20 | 4.31 | 100.00 |
| 14 | 41 | 5,292 | .24 | .19 | .15 | .49 | .19 | 14.47 | 64.39 | 17.88 | 2.00 | 100.00 |
| 15 | 42 | 6,614 | .26 | .05 | .29 | .38 | .20 | 12.99 | 61.85 | 21.83 | 2.15 | 100.00 |
| 16 | 31 | 5,240 | .27 | .60 | -- | .86 | 1.51 | 13.49 | 62.38 | 18.87 | 2.02 | 100.00 |
| 17 | 30 | 6,253 | .05 | .66 | .46 | 1.49 | 1.26 | 13.34 | 59.07 | 20.66 | 3.01 | 100.00 |
| 18 | 19 | 4,373 | .37 | 1.89 | .30 | 4.99 | 1.83 | 11.73 | 56.61 | 19.99 | 2.29 | 100.00 |
| 19 | 21 | 5,091 | .14 | .92 | 2.34 | 3.34 | 4.58 | 2.06 | 45.27 | 37.30 | 4.05 | 100.00 |
| 20 | 20 | 5,271 | .34 | 1.20 | 4.14 | 7.70 | 5.07 | 5.56 | 43.87 | 30.51 | 1.61 | 100.00 |
| 21 | 13 | 3,974 | .28 | .38 | 4.13 | 19.10 | 9.01 | 3.12 | 43.22 | 19.78 | .98 | 100.00 |
| 22 | 4 | 1,236 | -- | .65 | 1.62 | 20.63 | 10.11 | 1.54 | 42.31 | 20.55 | 2.59 | 100.00 |
| 23 | 4 | 1,433 | -- | .42 | 1.33 | 21.63 | 9.98 | 2.51 | 30.07 | 29.24 | 4.82 | 100.00 |
| 24 | 4 | 1,614 | -- | .50 | 2.42 | 41.13 | 9.11 | 5.58 | 30.66 | 9.67 | .93 | 100.00 |
| 25 | 3 | 1,276 | .39 | 1.96 | .39 | 37.30 | 10.27 | -- | 32.13 | 16.07 | 1.49 | 100.00 |
| 26 | 1 | 439 | -- | 2.51 | -- | 48.97 | 8.43 | 6.83 | 31.44 | 1.14 | .68 | 100.00 |
| 27 | 2 | 772 | -- | -- | .65 | 40.02 | 11.27 | 6.48 | 29.40 | 12.18 | -- | 100.00 |
| 28 | 1 | 432 | 1.16 | .93 | 1.62 | 36.57 | 5.09 | 3.24 | 31.25 | 14.12 | 6.02 | 100.00 |
| Average or total | 675 | 72,880 | .22 | .50 | .91 | 5.67 | 2.56 | 9.82 | 55.54 | 21.76 | 3.02 | 100.00 |

[1/] Percentages are actual values uncurved.

[2/] -- = No recovery in these lumber grades and diameter classes.

Table 4--*Young-growth ponderosa pine lumber grade recovery by lumber item size for all study logs*

| Lumber size | Lumber grades[1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Select | | | Factory lumber | | | Common | | | |
| | B and Better | C | D | Moulding | No. 3 Clear | Nos. 1, 2, and 3 Shop | Nos. 1 and 2 | No. 3 | No. 4 | No. 5 |
| Inches | Board feet | | | | | | | | | |
| 4/4[2] | --[3] | -- | -- | 4 | 73 | 870 | -- | 13 | 123 | -- |
| 5/4[2] | -- | -- | 13 | 51 | -- | 5,810 | -- | -- | 3 | -- |
| 1 x 4 | 6 | 21 | 81 | 42 | -- | -- | 715 | 2,826 | 1,550 | 763 |
| 1 x 6 | -- | 5 | 34 | 41 | 30 | -- | 660 | 5,366 | 2,468 | 322 |
| 1 x 8 | -- | -- | -- | 11 | -- | -- | 810 | 7,109 | 3,391 | 357 |
| 1 x 10 | -- | -- | -- | -- | -- | -- | 1,224 | 6,754 | 2,648 | 344 |
| 1 x 12 | -- | -- | -- | -- | 120 | -- | 4,220 | 20,124 | 6,098 | 504 |
| Total | 6 | 26 | 128 | 149 | 223 | 6,680 | 7,629 | 42,192 | 16,281 | 2,290 |

[1] Surface dry, graded under supervision of Western Wood Products Association lumber inspector.

[2] Mixed board widths.

[3] -- = No recovery in these lumber grades and size classes.

No. 3 Common was the largest lumber grade volume recovered. It represented 62.8 percent of the No. 4 Grade logs and 55.4 percent of the No. 5 grade logs. When both log grades are combined, recovery was 55.8 percent. In contrast, the recovery of this lumber grade from Grade 5 old-growth ponderosa pine logs was reported by Wise (1964) as 22 percent. That comparison is based on a similar range of log diameters for both studies. Yield differences such as these show the influence of changes in resource characteristics.

The No. 3 Common lumber accounted for 54.9 percent of the total lumber value from Grade 5 logs. Ponderosa pine is often considered for Shop grade lumber items. The Grade 5 logs in this young-growth timber yielded only 9.64 percent Shop and Moulding grades of lumber (table 3). Based on the lumber prices used in figure 3 calculations, this volume, however, represents 12.04 percent of the total lumber value from Grade 5 logs.

Log size and grade both have an influence on lumber grade recovery. Table 3 of uncurved grade recovery percentages shows this relationship for Grade 5 logs. Figure 1 for No. 3 Common lumber from Grade 5 logs further shows this relationship. The regression is based on log diameter class averages.

## *THE LUMBER RECOVERY RATIO (LRR)*

Accurate sawing of green lumber to provide for sawing variation, shrinkage, and minimum planing allowance will improve the recovery percentages that are usually expressed as overrun. Figure 2 shows the relationship of overrun to sawn log diameter for these 703 logs. The low $R^2$ value of 8.1 indicates a high degree of variation around the regression. Analysis of covariance showed no significant difference in slope or intercept between

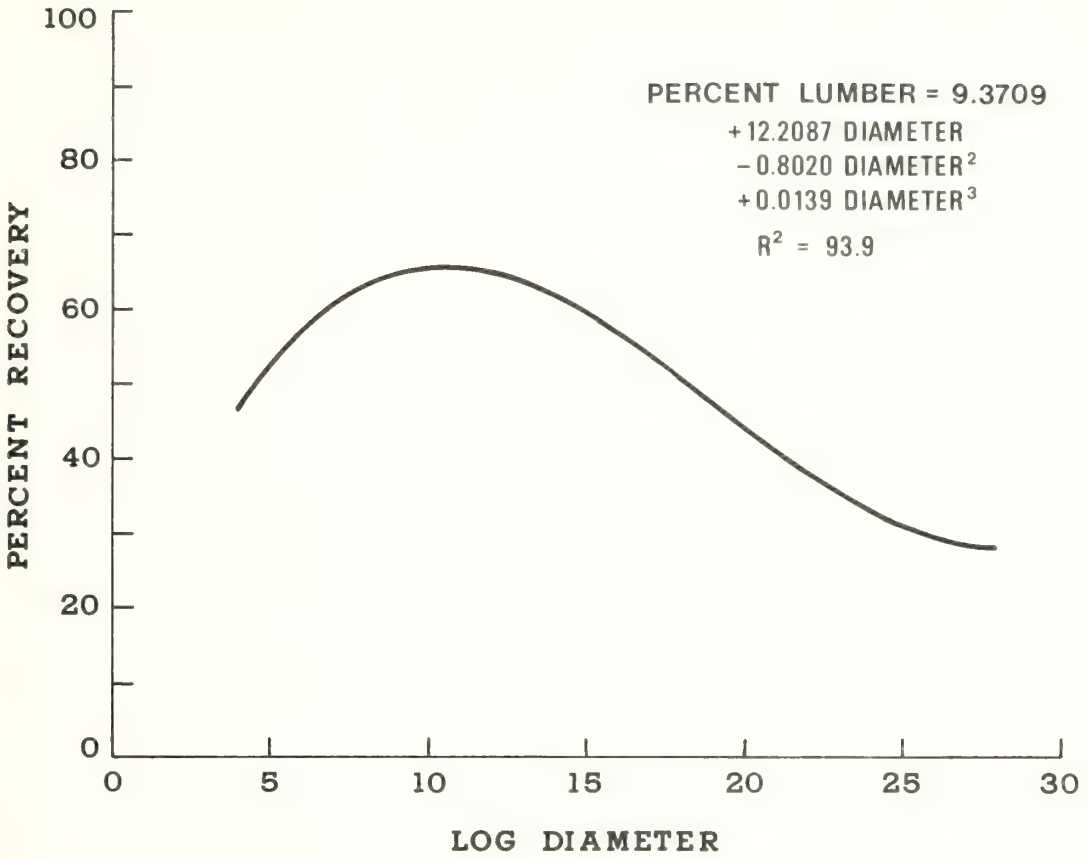



*Figure 1.--No. 3 Common lumber as a percentage of total surfaced dry lumber by diameter class averages for Grade 5 logs.*

Grade 4 and 5 logs; therefore, the common regression line is shown.

The reader is undoubtedly aware of the relationship of overrun to log diameter. This oddity of log measurement says that the estimate made as to what a log will produce in lumber--is not what gets produced. Any difference, higher or lower, is termed overrun or underrun as the case may be.

Plotted overrun data for the 703 sample logs emphasizes the variation in recovery and overrun from small sound logs. Scribner scale approaches zero overrun for logs in the 20- to 25-inch diameter classes. Estimates of lumber recovery for small diameter logs should be strongly tempered based on known overrun variability. This is especially evident for logs below 15 inches in diameter as shown in figure 2.

Some measurement of mill equipment efficiency and production is a necessary tool to the mill manager. Several reports have become available recently that present lumber recovery factors (LRF) and lumber recovery ratios (LRR) as production efficiency measurement tools (Dobie 1975, Fahey and Martin 1974, Fahey and Woodfin 1976, and Pong and Fahey 1973). An LRF of 6.46 was measured for this study based on surfaced dry lumber tally and log gross cubic volume (i.e., 6.46 board feet of lumber recovery on the average from every cubic foot of log input to the sawmill). The average

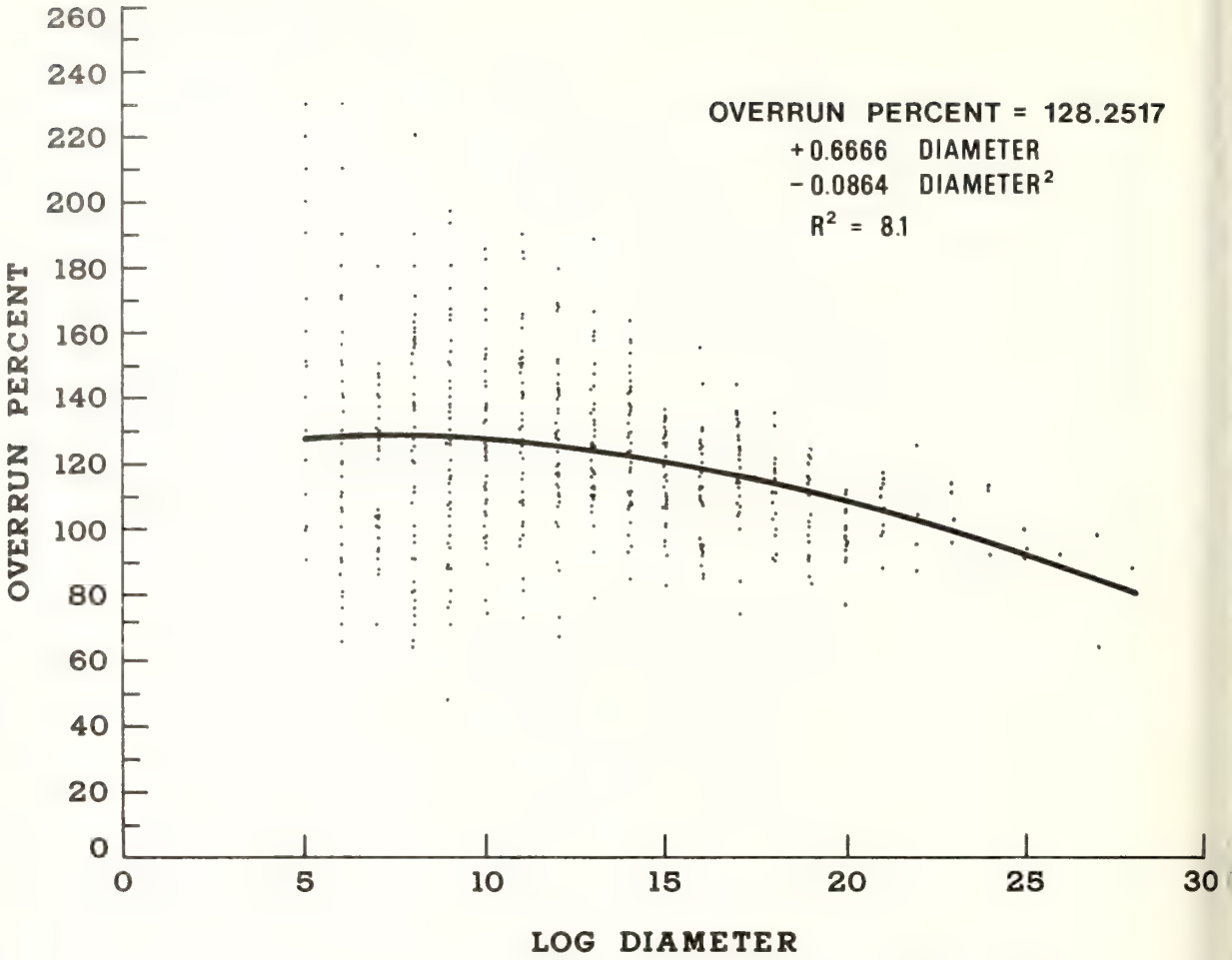



*Figure 2.--Overrun curve for combined log Grades 4 and 5--703 young-growth ponderosa pine logs.*

LRF for all sawmills in the United States has been estimated at 6.5 board feet (USDA Forest Service 1973a). The gross cubic volume was computed by the following formula:

$$\text{Volume} = \frac{\pi \, L \, (D_1^2 + D_1 \, D_2 + D_2^2)}{12 \times 144} \; ;$$

where, $\pi$ is the constant pi,
$D_1$ is average log diameter, large end,
$D_2$ is average log scale diameter, small end, and
L is log scaling length.

By definition 12 board feet of nominal 1-inch lumber is equivalent to 1 cubic foot of lumber. One cubic foot of surfaced dry 4/4-inch lumber, however, is approximately 15 actual board feet per cubic foot of lumber (25/32-inch surfaced board thickness = 0.78 inch and 12 ÷ 0.78 = 15.38). The average rough green thickness of lumber produced during this study was 32/32, a full inch. This resulted in 12.0 board feet lumber tally per cubic foot of lumber produced. For other studies we have conducted, these values have ranged from 11.69 to 13.95 board feet per cubic foot. A reduction of 1/32 inch in the rough green thickness for 1-inch lumber should theoretically increase actual

lumber recovery about 3 percent. For example, assuming full recovery of this 3 percent by accurate manufacturing, the increase would mean an additional 2,092 board feet of recovery in this study (103 percent x 69,727 = 71,819 board feet). Based on a $195/MBF lumber price, this extra volume is valued at nearly $408.00.

Changes in processing technology are reflected in Mueller and Kovner (1967) and Wise (1964). The average rough green 1-inch lumber sizes for those two studies were 34/32 to 35/32 and 35/32 respectively. Over 9 percent less wood (3/32) was required in cutting a 1-inch board from this study with the average lumber size of 32/32. In terms of lumber recovery, this means about 1 board foot more of lumber for each cubic foot of rough green lumber produced.

The 4/4-inch lumber accounted for 92.2 percent of the total lumber produced with the balance being 5/4-inch. If the LRR is recalculated to include a 3-percent increase in the volume of 4/4-inch lumber, lumber recovery ratio would increase from 55 to 57 percent. Such a potential increase in recovery from high valued logs is of concern to mill managers. Product grade yield and cubic recovery relationships as reported here can provide the basis for these evaluations.

## LOG AND TREE VALUE—CUBIC VOLUME

Average value of sawn logs in this study can be expressed in several terms. We are most familar with log values expressed as dollars per thousand board feet lumber tally ($/MLT) or as dollars per thousand board feet net Scribner log scale ($/MNS). Log grade values are shown in the following tabulation. A new term is included, dollars per hundred cubic feet of gross log volume sawn ($/100CFGL).

| Value | Log Grade 4 | Log Grade 5 | Trees |
|---|---|---|---|
| $/MLT | $182.54 | $180.80 | $180.86 |
| $/MNS | 211.60 | 206.96 | 207.12 |
| $/100CFGL | 120.92 | 116.76 | 116.91 |

Figure 3 shows the relationship of $/100 cubic feet to tree d.b.h. for this study. The calendar year 1973 U.S. Forest Service, California Region lumber prices were used:

| Lumber Grade | Price/MLT |
|---|---|
| B and Better Select | $501.57 |
| C Select | 493.39 |
| D Select | 373.06 |
| Moulding | 362.42 |
| No. 3 Clear | 293.28 |
| No. 1 Shop | 262.58 |
| No. 2 Shop | 226.29 |
| No. 3 Shop | 192.83 |
| 1 and 2 Common | 238.18 |
| 3 Common | 178.86 |
| 4 Common | 150.13 |
| 5 Common | 91.76 |

Study results can be illustrated graphically to show resource utilization by processing stages. When displayed as in figure 4, it is easier to appreciate the use of $/100 cubic feet as an expression of value recovered.

Figure 5 illustrates the percent of gross log volume that was produced as rough green lumber. As noted earlier, there was no significant difference between the Grade 4 and Grade 5 log recovery values. Therefore a common regression could be used. Both curves are shown, however, because the grades are considered separately in timber valuation and lumber grade yields.

## RECOVERY BY TREES

The first 16-foot log of every tree was Grade 5 log by Improved Ponderosa Pine Log Grading System (Gaines 1962). Only 28 of the 703

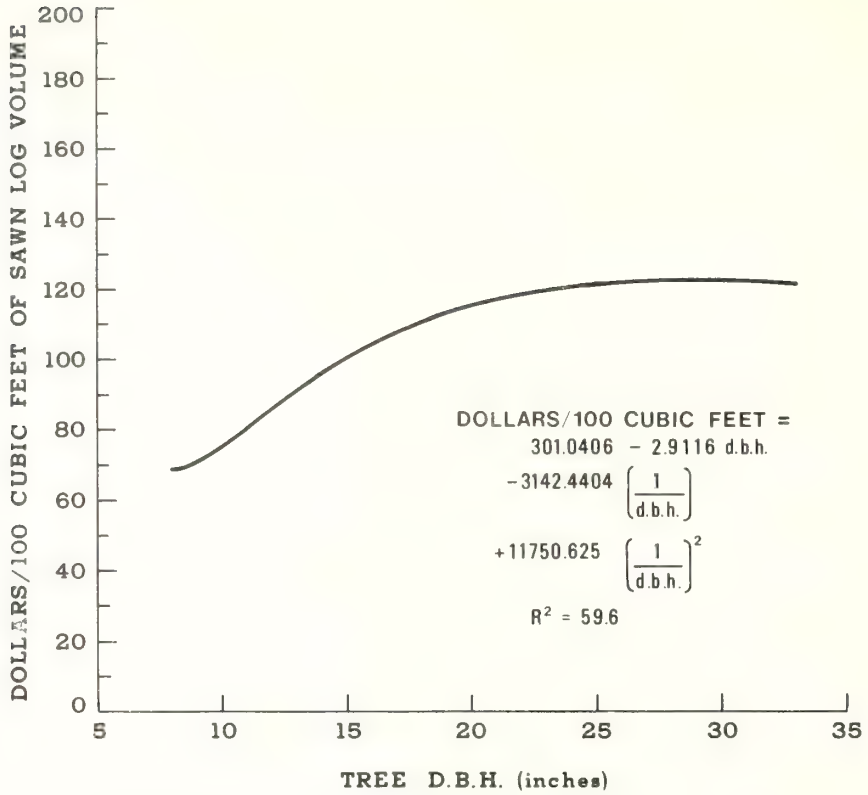



*Figure 3.--Young-growth ponderosa pine--tree gross realization in dollars per 100 cubic feet of sawn log volume by d.b.h. classes.*

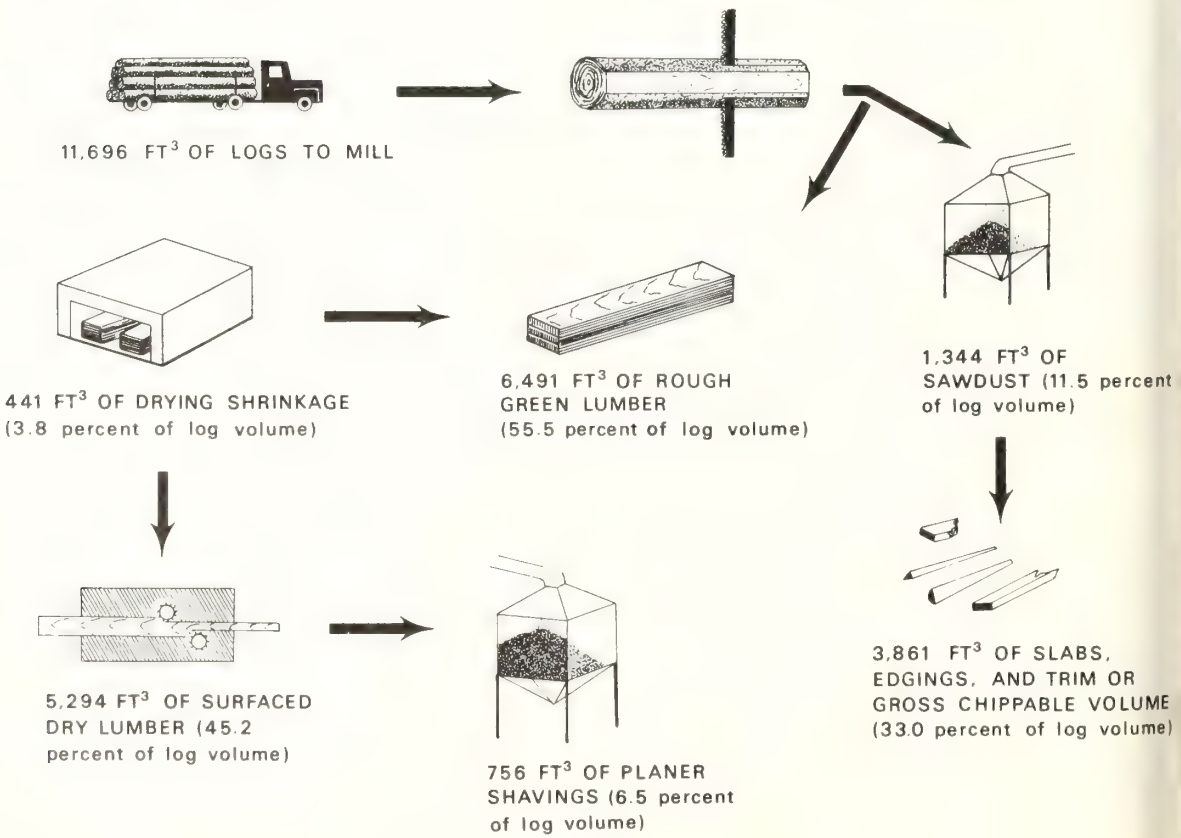

11,696 FT³ OF LOGS TO MILL
441 FT³ OF DRYING SHRINKAGE (3.8 percent of log volume)
6,491 FT³ OF ROUGH GREEN LUMBER (55.5 percent of log volume)
1,344 FT³ OF SAWDUST (11.5 percent of log volume)
5,294 FT³ OF SURFACED DRY LUMBER (45.2 percent of log volume)
756 FT³ OF PLANER SHAVINGS (6.5 percent of log volume)
3,861 FT³ OF SLABS, EDGINGS, AND TRIM OR GROSS CHIPPABLE VOLUME (33.0 percent of log volume)

*Figure 4.--Where cubic volume goes during lumber production.*

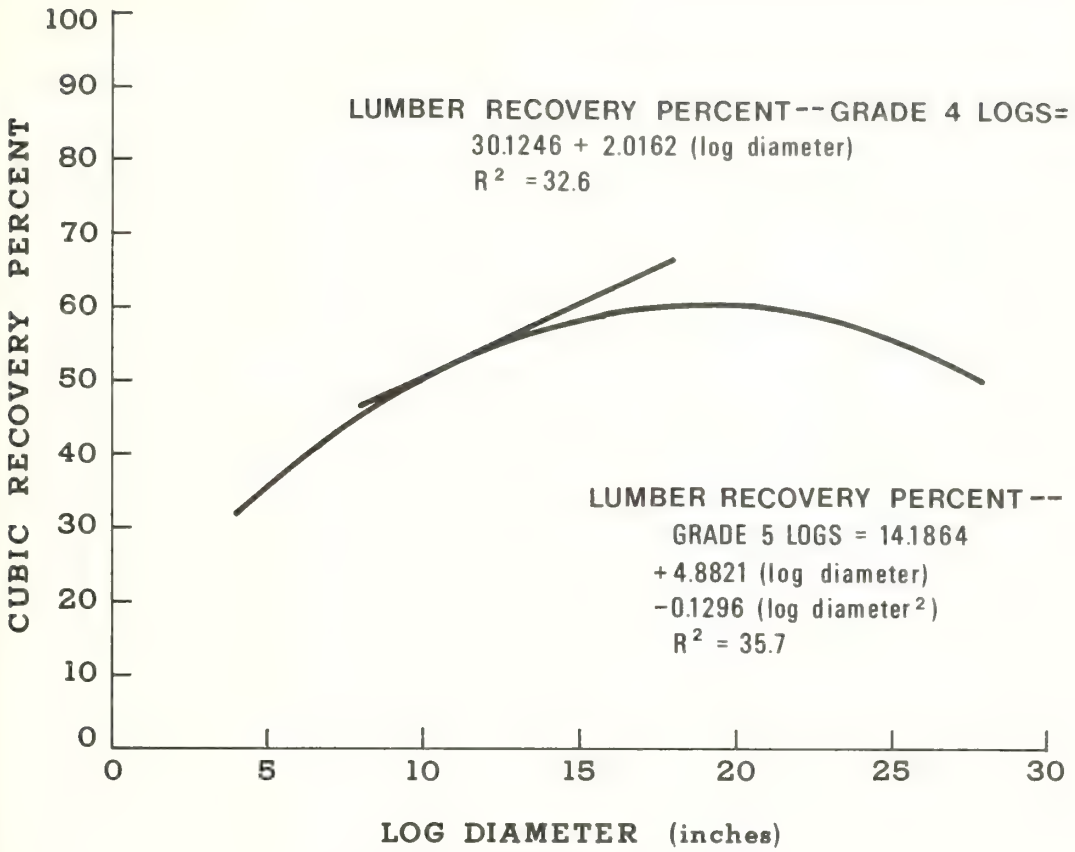



*Figure 5.--Percent of gross log volume produced as rough green lumber by log diameter--Grade 4 and 5 ponderosa pine.*

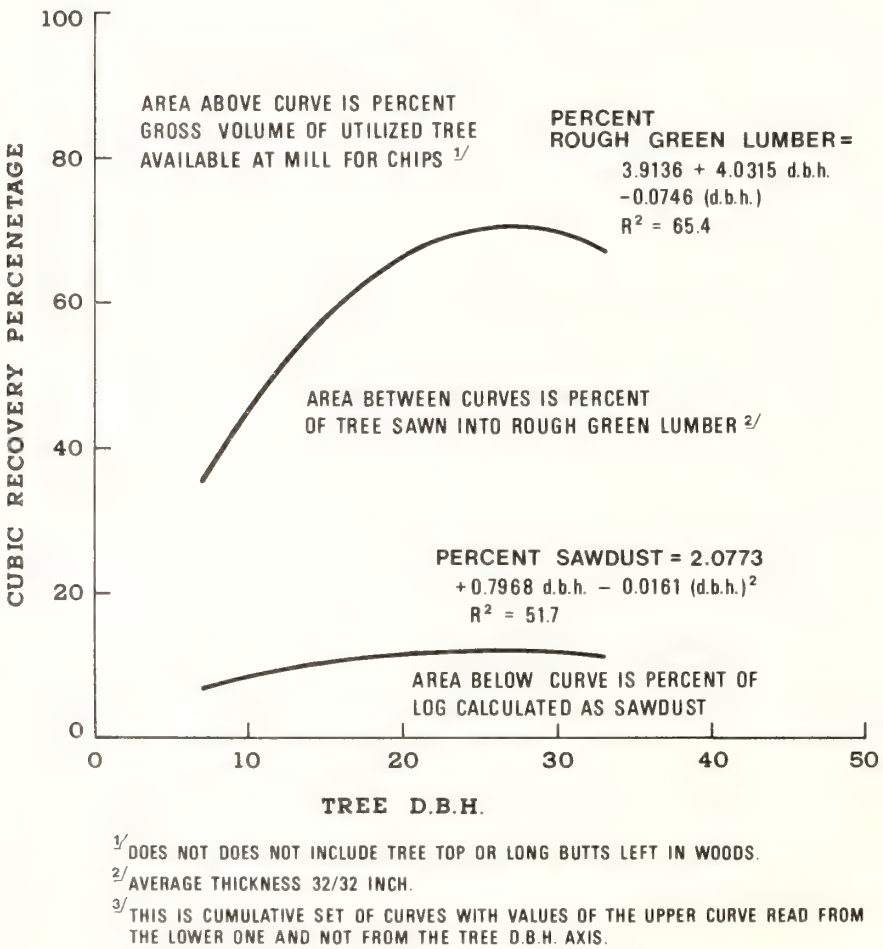
logs cut from these were Grade 4, the remainder were Grade 5 (fig. 6).

Regressions of cubic recovery percentage for rough green lumber and sawdust are presented in figure 7. The curves have been plotted in cumulative fashion in order to easily estimate volumes by tree diameter. For example, as read from figure 7, a 20-inch d.b.h. tree yielded the following estimated product amounts from the utilized portion that was delivered to the mill: 7.8 percent sawdust, 54.7 percent rough green lumber (62.5 - 7.8), and 37.5 percent available for chips (100.0 - 62.5).

Table 5 shows the distribution of lumber grade recovery percentages by tree diameter. The reader is reminded that the number of sample trees in the larger diameters is limited; therefore, the recovery values from prediction equations in this range should be viewed with caution for their accuracy.

The variation in cubic recovery due to log and tree sizes is illustrated by the rough green lumber curve in figure 7. Cubic recovery averaged 55 percent for all logs but ranged from 39 percent for 5-inch logs to 63 percent for 18-inch logs. These relationships should be of concern to any forest products industry installation heavily involved in utilization of small timber. The cubic recovery percentage for all logs is shown in figure 5.

*Figure 6.--Representative ponderosa pine in tree sample area. Limbyness was characteristic of stand.*




1/ DOES NOT DOES NOT INCLUDE TREE TOP OR LONG BUTTS LEFT IN WOODS.

2/ AVERAGE THICKNESS 32/32 INCH.

3/ THIS IS CUMULATIVE SET OF CURVES WITH VALUES OF THE UPPER CURVE READ FROM THE LOWER ONE AND NOT FROM THE TREE D.B.H. AXIS.

*Figure 7.--Percent of utilized tree cubic volume recovered as rough green lumber, produced into sawdust, and available for chipping.*

Table 5--*Surfaced dry lumber grade recovery by tree diameter classes for young-growth ponderosa pine*[1/]

| D.b.h. | Number of trees | Lumber tally | Lumber grades | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | D and Better Select | Moulding and No. 3 Clear | Shop | | | Common | | | | |
| | | | | | No. 1 | No. 2 | No. 3 | Nos. 1 and 2 | No. 3 | No. 4 | No. 5 | |
| Inches | | Board feet | Percent | | | | | | | | | |
| 8 | 4 | 66 | --[2/] | -- | -- | -- | -- | 7.58 | 69.69 | 18.18 | 4.55 | 100.00 |
| 9 | 3 | 79 | -- | 5.06 | -- | -- | -- | 6.33 | 58.23 | 24.05 | 6.33 | 100.00 |
| 10 | 8 | 325 | -- | -- | -- | -- | -- | 18.15 | 49.54 | 21.23 | 11.08 | 100.00 |
| 11 | 12 | 670 | -- | .75 | -- | -- | -- | 18.06 | 50.30 | 25.07 | 5.82 | 100.00 |
| 12 | 8 | 537 | -- | -- | -- | -- | -- | 15.83 | 55.87 | 23.09 | 5.21 | 100.00 |
| 13 | 5 | 687 | .58 | .58 | -- | -- | -- | 7.42 | 53.72 | 31.30 | 6.40 | 100.00 |
| 14 | 6 | 847 | -- | -- | -- | -- | -- | 17.00 | 61.16 | 17.47 | 4.37 | 100.00 |
| 15 | 13 | 2,388 | -- | -- | -- | -- | -- | 9.92 | 63.07 | 25.00 | 2.01 | 100.00 |
| 16 | 8 | 1,872 | .27 | -- | -- | -- | .59 | 10.20 | 60.95 | 24.20 | 3.79 | 100.00 |
| 17 | 7 | 1,853 | .16 | -- | -- | -- | -- | 14.03 | 65.68 | 17.32 | 2.81 | 100.00 |
| 18 | 10 | 3,163 | .22 | -- | -- | -- | -- | 9.42 | 63.99 | 22.86 | 3.51 | 100.00 |
| 19 | 5 | 2,087 | .38 | -- | -- | -- | 1.92 | 10.21 | 62.67 | 20.70 | 4.12 | 100.00 |
| 20 | 10 | 4,710 | .70 | .13 | .17 | .28 | -- | 15.69 | 64.20 | 15.94 | 2.89 | 100.00 |
| 21 | 9 | 4,568 | .07 | .07 | .11 | .20 | .33 | 10.99 | 64.02 | 22.02 | 2.19 | 100.00 |
| 22 | 6 | 3,067 | .33 | -- | .26 | .42 | .33 | 11.44 | 64.23 | 19.24 | 3.75 | 100.00 |
| 23 | 6 | 4,120 | .10 | .78 | 1.17 | 1.26 | 1.50 | 9.05 | 56.91 | 27.26 | 1.97 | 100.00 |
| 24 | 14 | 9,632 | .16 | .42 | .35 | 1.10 | 1.37 | 12.19 | 58.85 | 21.97 | 3.59 | 100.00 |
| 25 | 3 | 2,242 | .13 | .45 | -- | 1.47 | 1.34 | 10.35 | 59.01 | 22.48 | 4.77 | 100.00 |
| 26 | 8 | 6,135 | .29 | .80 | 3.52 | 1.47 | .83 | 14.20 | 54.95 | 21.22 | 2.72 | 100.00 |
| 27 | 7 | 5,737 | .16 | .16 | 2.81 | 6.80 | 4.17 | 4.65 | 51.49 | 27.58 | 2.18 | 100.00 |
| 28 | 5 | 4,055 | .29 | 1.97 | 1.53 | 4.64 | 3.13 | 9.69 | 48.91 | 27.42 | 2.42 | 100.00 |
| 29 | 2 | 1,961 | .15 | 2.39 | 1.48 | 9.74 | 1.68 | 13.16 | 52.63 | 16.78 | 1.99 | 100.00 |
| 30 | 3 | 3,686 | .08 | .38 | .68 | 13.84 | 10.96 | 2.50 | 49.58 | 17.88 | 4.10 | 100.00 |
| 31 | 4 | 4,913 | .08 | .49 | .73 | 19.19 | 4.76 | 2.95 | 45.63 | 23.65 | 2.52 | 100.00 |
| 32 | 3 | 4,969 | .20 | .62 | .50 | 23.65 | 8.63 | 10.44 | 41.62 | 11.99 | 2.35 | 100.00 |
| 33 | 1 | 1,235 | .40 | 1.13 | 1.21 | 33.69 | 5.02 | 3.56 | 39.45 | 13.60 | 1.94 | 100.00 |
| Average or total | 170 | 75,604 | .21 | .49 | .89 | 5.46 | 2.49 | 10.09 | 55.81 | 21.53 | 3.03 | 100.00 |

[1/] Percentages are actual values uncurved.

[2/] -- = No recovery in these lumber grades and diameter classes.

## Summary

Young-growth ponderosa pine yielded about 56 percent of the lumber recovery volume in grade No. 3 Common lumber and 25 percent in grades Nos. 4 and 5 Common lumber combined. An average of 55.5 percent of the log volume was recovered as rough green lumber, 11.5 percent went to sawdust, and 33.0 percent was available for chipping. Lumber recovery factor (LRF was 6.46 board feet of surfaced dry lumber recovery per cubic foot of log input. The lumber recovery ratio (LRR was 0.55 cubic feet of rough green lumber per cubic foot of log volume.

## Summary of Log Grade Specifications Defects Permitted

| Grade | Primary (log knots) | Secondary (scars, etc |
|---|---|---|
| 1 | One log knot not over one-half-inch diameter | Confined to three panels or less |
| 2 | Confined to four panels or less | Secondary plus primary confined to six panels |
| 3 | Six panels free of all grading defects | |
| 4 | (a) 80 percent bark limbs<br>(b) Bark limbs not exceeding one-sixth log diameter.<br>Other log knots not exceeding one-twelfth log diameter<br>(c) Not more than 24 limbs near maximum size | Confined to 3 panels or less |
| 5 | All other logs, if net scale one-third or more of gross | |

## General Specifications (Gaines 1962) and Definitions

1. Apply to 16-foot logs as cruised.
2. Must be live logs with one-third net scale.
3. Grading defects apply without reference to scaling practice.
4. Grading defects are log-surface abnormalities that influence quality of lumber sawn from log.
5. Primary defects are "log-knots", limbs, stubs, limb holes, overgrown knots.
6. Secondary defects are scars, large or unsound burls, forks, crooks, cracks, cankers.
7. Log knots within scars are disregarded if 2 in. or smaller and 5 in. or more below normal wood surface; otherwise they are counted.
8. False defects (disregard) are small sound burls, bumps, flutes or flanges, bird peck, minor bark distortions.
9. Indeterminate defects (disregard) are sweep, spiral, grain.
10. A panel is one-fourth circumference, 4 feet long. May be scattered over log but must not overlap.
11. Primary defect takes precedence over secondary on any panel.

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GPO 985-389

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Young-growth ponderosa pine logs from the Shasta-Trinity National Forest yielded 78 percent of volume in No. 3 and 4 Common grade lumber. Cubic recovery information and lumber grade recovery by log diameter classes are presented for the Grade 4 and 5 logs.

KEYWORDS: Lumber grading, lumber recovery, ponderosa pine, *Pinus ponderosa*, young growth, California (northern).

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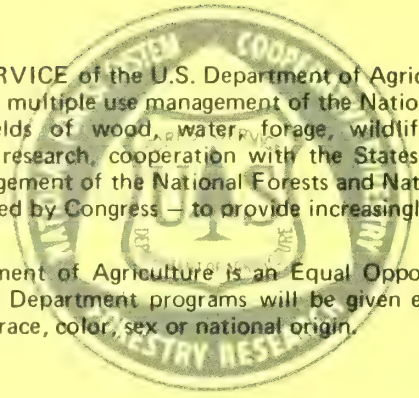

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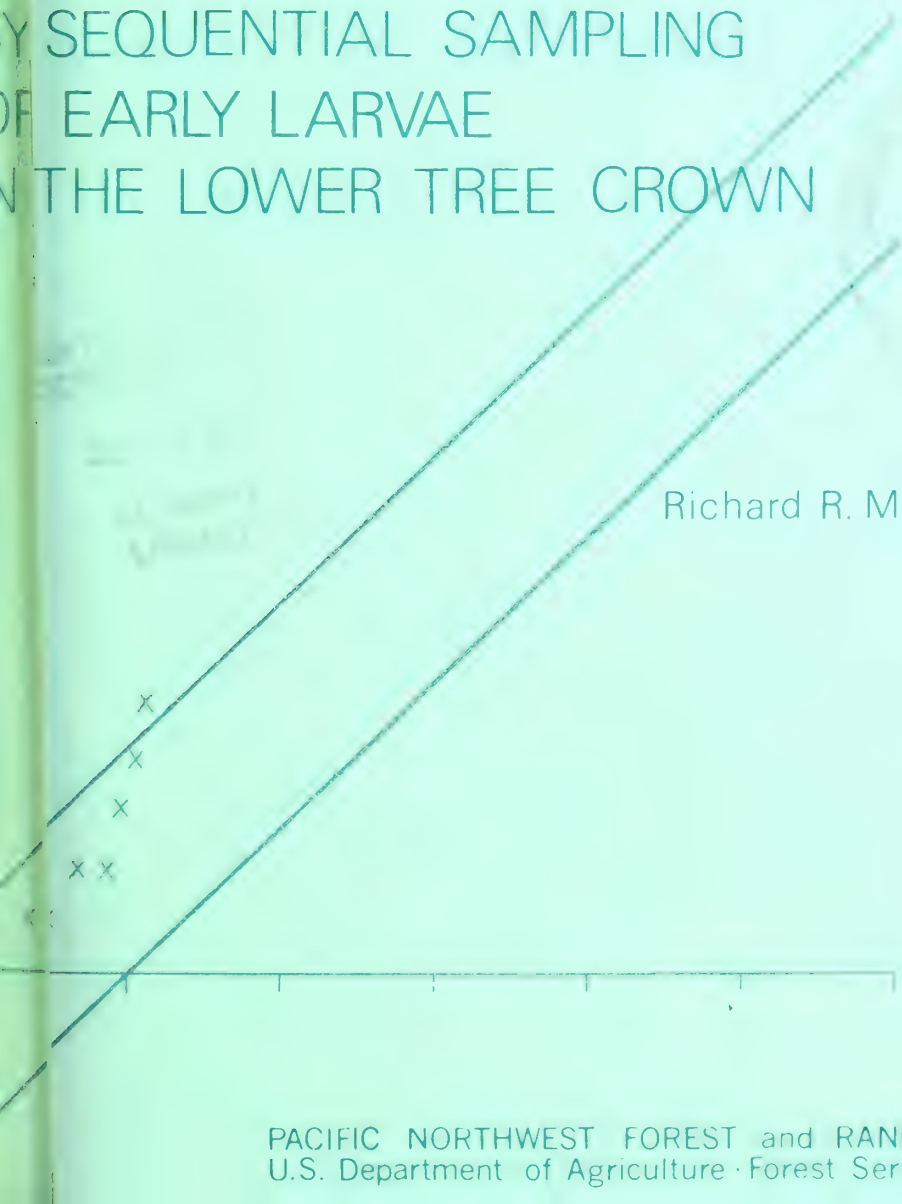
USDA Forest Service Research Paper PNW-238
1978

# DETECTING SUBOUTBREAK POPULATIONS OF THE DOUGLAS-FIR TUSSOCK MOTH BY SEQUENTIAL SAMPLING OF EARLY LARVAE IN THE LOWER TREE CROWN

Richard R. Mason



PACIFIC NORTHWEST FOREST and RANGE EXPERIMENT STATION
U.S. Department of Agriculture · Forest Service Portland, Oregon

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# DETECTING SUBOUTBREAK POPULATIONS OF THE DOUGLAS-FIR TUSSOCK MOTH BY SEQUENTIAL SAMPLING OF EARLY LARVAE IN THE LOWER TREE CROWN

*Reference Abstract*

Mason, Richard R.
1978. Detecting suboutbreak populations of the Douglas-fir tussock moth by sequential sampling of early larvae in the lower tree crown. USDA For. Serv. Res. Pap. PNW-238, 9 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A sequential sampling plan is described for identifying tussock moth populations which, at a maximum expected rate of increase, could be within 1 year of outbreak status. The plan uses a new technique of sampling early larvae by the nondestructive examination of lower crown foliage. Larvae at inconspicuous low densities are classified into relatively low or high categories by their frequency of occurrence on foliage samples. The sampling plan is applied independently on individual plots to classify the density of each plot. It is an appropriate method for quickly screening suboutbreak populations in ground evaluation surveys.

KEYWORDS: Population sampling, insect populations, Douglas-fir tussock moth, *Orgyia pseudotsugata*, insect surveys.

*RESEARCH SUMMARY*

*Research Paper PNW-238*

*1978*

Low density populations of tussock moth are usually evaluated in terms of the density of young larvae on the foliage. Estimates of larval density with a high level of precision, however, are unnecessary for most survey purposes. A general classification of density that is biologically meaningful can be substituted and is easier to determine than a precise estimate.

A rationale has been developed for classifying larval numbers, which are presently inconspicuous on the foliage, into either a low-level population which, at a maximum rate of expected increase, is at least 2 years away from causing visible tree defoliation; or a suboutbreak population which has the potential of increasing to an outbreak level in 1 year. The categories are especially useful for evaluating known populations of tussock moth suspected of having an upward trend in numbers.

A sequential sampling plan was derived for field classification of plots into either the low-level or suboutbreak category. Sampling is by nondestructive examination of the lower crown foliage of randomly selected trees on a plot. A design for a pocket tally sheet with the built-in sequential plan is also given. Using the sequential plan one person can determine the present status of a larval population on a plot with only a fraction of the amount of sampling normally required for evaluation.

## Introduction

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and many of the true firs, *Abies* spp., in Western North America. Outbreaks erupt suddenly and often synchronously in patches over large forested areas. The early recognition of impending outbreak conditions is essential for planning control activities to prevent tree damage during the 1st year of heavy defoliation (Wickman 1978).

Low-density populations of the Douglas-fir tussock moth do not cause tree defoliation that can be detected by aerial observation; therefore, preoutbreak numbers can only be evaluated from the ground by trapping male moths or examining foliage for other life stages. A standard criterion for ground evaluation is the density of young larvae (1st-2d instars) newly established on the foliage in the spring or early summer. Methods have been developed for making precise estimates of density by sampling foliage from branches in the middle portion of the tree and expressing the number of larvae in terms of 1,000 square inches[1] of branch area (Mason 1970). Midcrown foliage is usually sampled by clipping 46-cm (18-in) branches with a pole-pruner and collecting the samples in a basket attached to the pole. This method has recently been modified for low-density populations by a nondestructive sampling technique relating density in the lower crown to density in the standard midcrown (Mason 1977). Such methods of estimating density, however, are time consuming and usually impractical for conducting large scale ground surveys.

Estimates of larval density with high levels of precision are often not necessary to evaluate population status. This is especially true for low densities which, even at a potentially maximum rate of population growth, may be more than 1 year away from an outbreak level. In such cases, the classification of larval densities on sample plots into biologically meaningful categories may be the only information needed from the initial survey. Sequential sampling is particularly appropriate for these situations because population densities are only classified, usually at a considerable saving in time and effort over conventional sampling methods. If additional detail is required for plots in a particular density class, estimates with a desired level of precision can still be made after populations in that class have been screened by the sequential survey.

Sequential analysis was first developed during World War II as a rapid method for making statistical evaluations (Statistical Research Group, Columbia University 1957; Wald 1947). Its value in biology was quickly recognized, and the method was soon recommended for conducting forest insect surveys (Oakland 1951, Stark 1952, Waters 1955). Sequential sampling plans for classifying populations have since been prepared for a variety of forest insects (Waters 1974). Plans are also available for classifying eggs and larvae of the Douglas-fir tussock moth by destructive sampling of branches (Mason 1969). Methods of constructing sequential plans and their uses in pest management have been adequately described by Onsager (1976) and Waters (1955). In this paper a sequential sampling plan is given for rapid identification of low-density populations of tussock moth larvae that may be only one generation removed from an outbreak level. Sampling is done by nondestructive examination of foliage in the lower tree crown.

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[1] Metric equivalent of 1,000 $in^2$ is 0.6452 $m^2$.

## Rationale for Population Density Classes

Tree defoliation by the tussock moth is not usually conspicuous until the average population density reaches about 20 early instars per 1,000 $in^2$, although higher densities are required to cause significant tree damage (Wickman 1978). Populations which attain the threshold density where defoliation is easily visible have traditionally been called "outbreaks." During the years of population increase preceding an outbreak, the maximum multiplication rate between generations is usually less than 10 and has averaged about 7 for the infestations studied in detail (Mason 1974; in press). At an annual multiplication rate of 7, therefore, populations with an average density of small larvae $>20/1,000$ $in^2$ must have a density $\geq 3.0/1,000$ $in^2$ 1 year before the first visible defoliation. Populations with densities $\leq 1.0/1,000$ $in^2$ are at least 2 years away from causing visible defoliation. In other words, low-density populations $>3.0/1,000$ $in^2$ could be in a release year; i.e., they have the potential of reaching outbreak status by the next generation if they have the maximum expected rate of increase. Population densities $\leq 1.0/1,000$ $in^2$, on the other hand, have only a slight chance of becoming an outbreak for at least 2 years.

The above threshold densities are useful for evaluating results from ground surveys because they identify populations that could be entering a release phase of an outbreak and separate them from populations that are still at a relatively insignificant level. Therefore, these thresholds were set as the class limits in a two-class sequential plan. Two hypotheses for the plan are

$H_1$: $M \leq 1.0$ larva/1,000 $in^2$; i.e., *low-level* population at least 2 or more years away from outbreak; and

$H_2$: $M \geq 3.0$ larvae/1,000 $in^2$; i.e., *suboutbreak* population potentially 1 year away from outbreak;

where

M = mean number of larvae/1,000 $in^2$ of branch area in the midcrown.

## The Primary Sample Unit

All sampling is done on lower branches of trees within reach from the ground. The primary sample unit is three 46- to 56-cm (18- to 22-in) branches per tree examined in place by rapping each with a stick over a hand-held drop cloth. Larvae that drop from the foliage are easily observed on the cloth. A drop cloth of dimensions of 61 by 122 cm (24 by 48 in) supported underneath at the corners by a pair of cross sticks has been used satisfactorily.

The proportion of primary sample units that are infested (i.e., one or more larvae per sample unit) is an adequate index of the standard midcrown density (Mason 1977). Midcrown density of 1st and 2d instars can be estimated from the frequency of occurrence of larvae on lower crown sample units by

$$\hat{M} = -4 \ln(1-p);$$

where

$\hat{M}$ = estimate of M and

p = the true proportion of lower crown sample units that are infested.

Class limits designated for the sequential plan can be expressed in terms of the proportion of primary sample units infested by substituting and solving for p in the above equation (fig. 1). The hypotheses

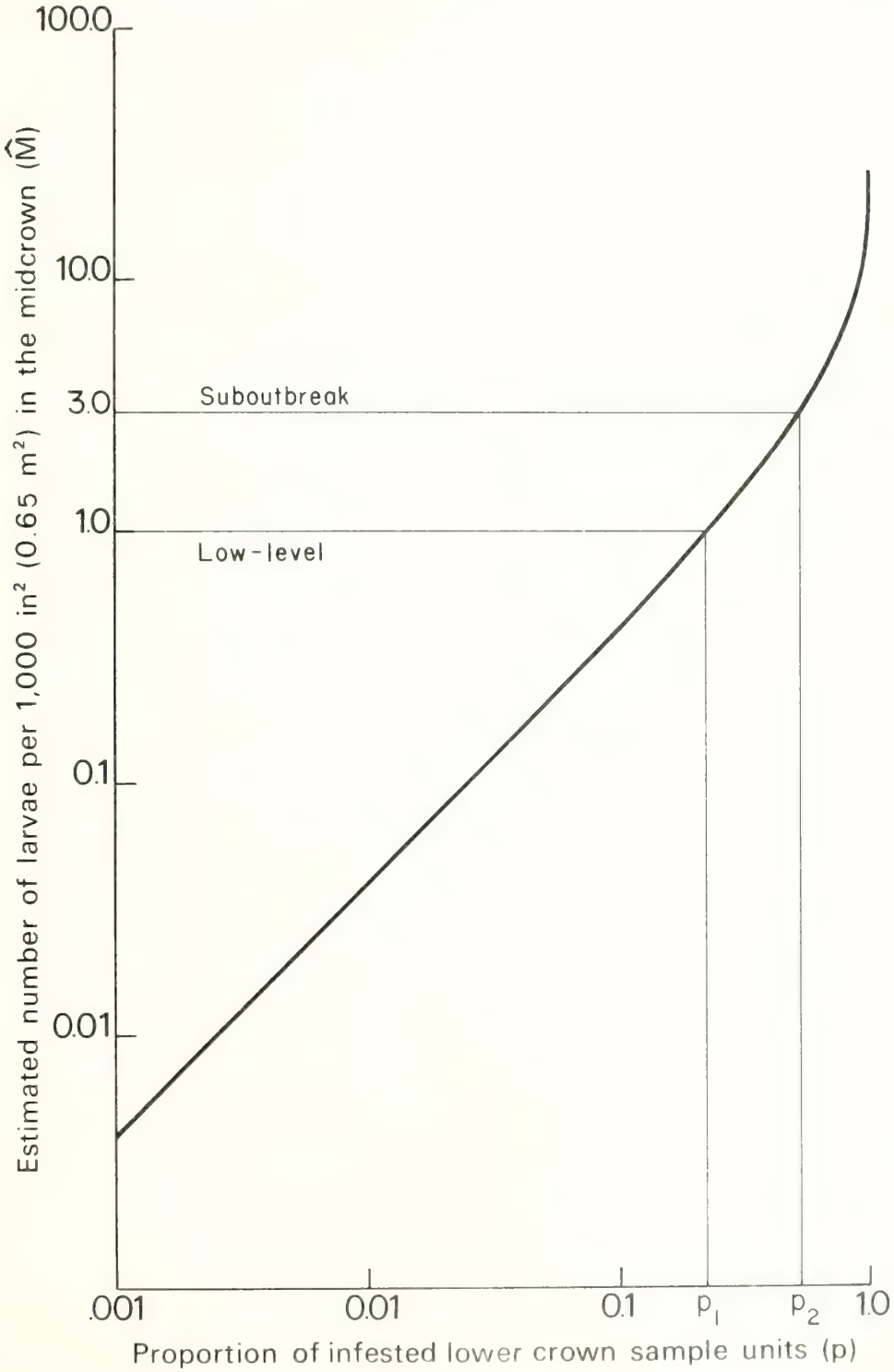


*Figure 1.--Relationship of midcrown density to proportion of infested lower crown sample units plotted on logarithmic scale (modified from Mason 1977).*

stated in terms of p then become

$H_1$ : $p \leq 0.2212$ and

$H_2$ : $p \geq 0.5276$.

The parameter p is estimated by the presence or absence of larvae on sample units; therefore, the binomial distribution, which assumes that every sample unit has an equal probability of being infested, is used for calculating the sequential plan.

## Sequential Decision Plan

Construction of the sequential plan requires selection of risk levels for making incorrect decisions. These are usually referred to as alpha ($\alpha$), the risk of rejecting a hypothesis when it is true, and beta ($\beta$), the risk of accepting a hypothesis when it is false. In this plan both allowable risks were set at 0.05 which means the maximum chance of mislabeling a population is 1 in 20.

Two parallel decision lines are used for testing the formulated hypotheses. These are calculated according to the equation for a straight line,

$$d_{1,2} = bn \pm a_{1,2} ;$$

where

d = cumulative number of infested sample units,

n = total number of trees sampled,

b = slope of the lines, and

a = the Y-intercept.

The slope and intercepts were calculated from the general formulas below given by Waters (1955) for sampling a binomial distribution.

Slope:

$$b = \frac{\log\left(\frac{1-p_1}{1-p_2}\right)}{\log \frac{p_2}{p_1}\left(\frac{1-p_1}{1-p_2}\right)} .$$

Intercepts:

$$a_1 = \frac{\log\left(\frac{1-\alpha}{\beta}\right)}{\log \frac{p_2}{p_1}\left(\frac{1-p_1}{1-p_2}\right)};$$

$$a_2 = \frac{\log\left(\frac{1-\beta}{\alpha}\right)}{\log \frac{p_2}{p_1}\left(\frac{1-p_1}{1-p_2}\right)};$$

where

$p_1$ = the proportion specified as the upper limit of the lower-level class ($H_1$), and

$p_2$ = the proportion specified as the lower limit of the suboutbreak class ($H_2$).

After solving for the slope and intercepts, the equations for the two decision lines are:

$d_1 = 0.365n - 2.151$ (lower line);

$d_2 = 0.365n + 2.151$ (upper line).

These lines are plotted in figure 2 which represents the sequential decision plan for testing hypotheses $H_1$ and $H_2$. If the cumulative number of infested sample units falls below the lower line for a given random sample of trees, $H_1$ is accepted and the tussock moth population is classified "low-level." If the cumulative number of infested units is above the upper line for the number of sampled trees, $H_2$ is accepted and the population is classified "suboutbreak." Intermediate values of infested sample units require that random sampling of trees continue until a decision line is crossed. If no decision is reached, the plan may call for sampling to be truncated after some arbitrary number of trees has been examined and the population is classified "intermediate."

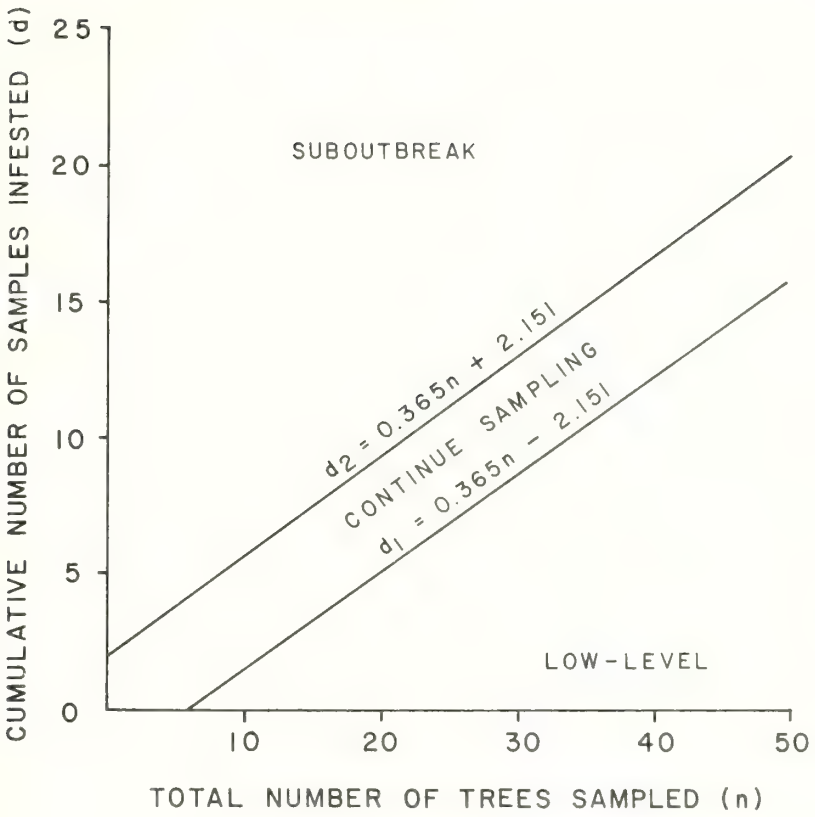


*Figure 2.--Sequential graph for sampling early larvae of the Douglas-fir tussock moth in the lower tree crown.*

Performance of the sequential plan can be evaluated in advance of actual sampling from the operating characteristic (OC) and average sample number (ASN) curves. These have been calculated from formulas published by the Statistical Research Group, Columbia University (1957) and are plotted in figure 3. Similar formulas for calculating OC and ASN curves are given by Waters (1955) and Onsager (1976).

The OC curve shows the probability of accepting $H_1$ for different values of p. If $p = p_1 = 0.22$ which is the upper class limit for a low-level population, the probability of accepting $H_1$ is 0.95 and the probability of rejection ($\alpha$) is 0.05. The chance of accepting $H_1$ for lower values of p is even higher than 0.95. Conversely, if $p = p_2 = 0.53$ which is the lower limit of a suboutbreak population, the probability of accepting $H_1$ is 0.05 ($\beta$) and the probability of rejection is 0.95. The risk of classifying a population density >3.0/1,000 $in^2$ as anything but "suboutbreak" is very small. Intermediate densities are more difficult to classify--such as a density of 1.8 larvae/1,000 $in^2$ ($p = 0.36$) which has an equal chance of classification in either category.

The ASN curve shows the average number of trees that need to be examined to reach a decision. The fewest trees are needed for densities within the class limits and the most trees for

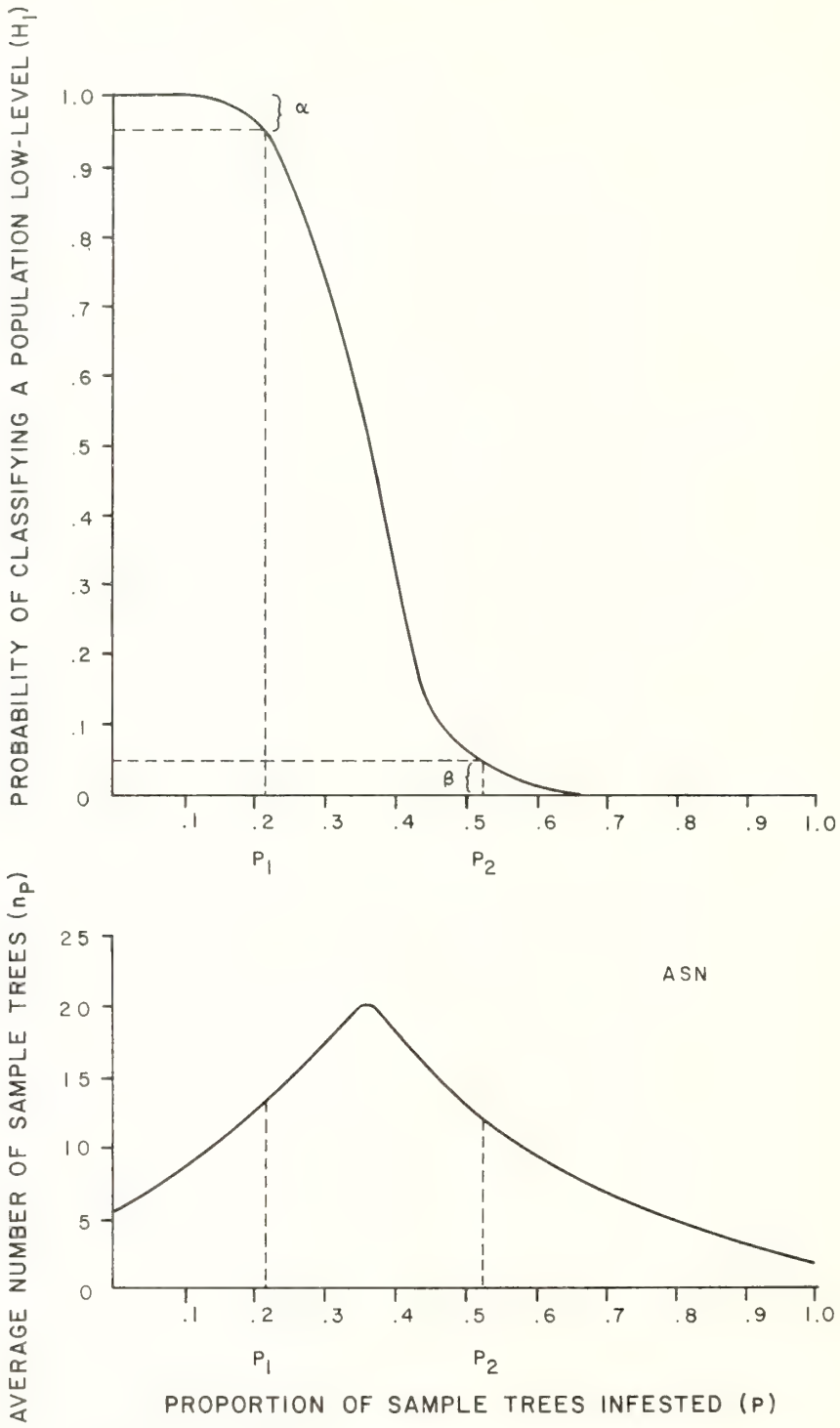


*Figure 3.--Operating characteristic (OC) and average sample number (ASN) curves for sequential sampling early larvae in the lower crown.*

intermediate densities. Obviously, the greatest savings from use of the sequential plan come from sampling larval densities clearly in one class or the other and the least savings from borderline densities.

## Field Use of the Plan

An underlying assumption in sequential analysis is that sample trees have been selected randomly; i.e., each tree on the plot where the insect population is being evaluated has an equal chance of being chosen. If a plot is about 2 ha (4.9 acres) in size, then each eligible tree in that 2 ha is assumed to have an equal chance of being selected for the sample. This theoretical assumption can be satisfied in the field by using a randomized procedure, such as a random numbers table or rolling dice, to determine the direction and distance between successive sample trees. For example, after one tree has been sampled, the direction (azimuth) and distance to the next tree is quickly determined from two random numbers. Units of measure can be scaled so that sample trees are sure to fall within the plot area. Trees might also be selected by gridding the plot on paper and randomly choosing coordinates to locate sampling spots. Because decisions of classification are based on sample units chosen at random and examined in sequence, trees must be sampled in order of their random selection and not by the shortest travel route between trees.

Trees selected for sampling need at least three lower branches suitable for the sample unit. Such branches must be well foliated and current needles available to feeding larvae; otherwise they would not be an acceptable habitat for early instars.

Graphs or tables with the sequential plan are awkward to use in the field. A field tally sheet which incorporates the calculated numerical values of the sequential plan is illustrated in figure 4. This sheet can be conveniently carried by a sampler in a pocket-size tally book; this leaves both hands free for holding the drop cloth and rapping stick. The class limits for decisionmaking are printed in the squares across the top of the columns for the number of trees sampled. The top left corner gives the upper limit of a "low-level" population and the bottom right corner the lower limit of a "suboutbreak" population.

As trees are sampled on each plot, the number of primary sample units that are infested is accumulated across the page. When the cumulative total equals or is less than the top value in the overhead box, sampling is terminated and the plot is classified "low-level" (e.g., plots A and B in fig. 4). When the cumulative total equals or is more than the bottom value, the plot is classified "suboutbreak" (e.g., plots C and D). If a decision is not reached after 20 trees, sampling is terminated and the plot classified "intermediate" (e.g., plot E).

Time of sampling is particularly important because the sequential plan is based on an evaluation when the majority of larvae are expected to be in the first instar, having only recently dispersed from hatched eggs onto new foliage. Sampling too early or too late will result in an inaccurate survey. Unfortunately, considerable variation occurs in the time of egg hatch and dispersal of larvae because of seasonal and physiographic differences. Wickman (1976a, 1976b) found that egg hatch and larval development are closely related to tree phenology and that sampling for small larvae can be properly timed by observing shoot development. In Oregon and California, the proper time for sampling newly established small larve is when all buds on host species have burst and average growth of new shoots has reached 1 to 2 inches.

| PLOTS | Cumulative number of trees | | | | | | | | | | | | | | | | | | | | CLASS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | | |
| | LOW / SUB | | | 4/- | 4/- | 5/0 | 5/0 | 6/0 | 6/1 | 6/1 | 7/1 | 7/2 | 7/2 | 8/2 | 8/3 | 8/3 | 9/4 | 9/4 | 10/4 | 10/5 | | |
| A | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | L | |
| B | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | | | | | | L | |
| C | 1 | 2 | 3 | 4 | | | | | | | | | | | | | | | | | S | |
| D | 0 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 4 | 5 | 6 | 6 | 7 | | | | | | | | S | |
| E | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 6 | I | |

*Figure 4.--Field tally sheet with examples for sequential sampling early larvae of the Douglas-fir tussock moth.*

## Discussion

This sequential plan is not intended for a single evaluation of a large forest area. Instead, it is recommended simply as a quick substitute for precise sampling on individual plots expected to have a relatively homogenous population. The number of plots needed to evaluate a large area will depend on numerous considerations including the design and purpose of the survey, distribution of habitat types, and variability in the insect population.

Acceptance of $H_2$ and the classification of a suboutbreak density are not a prediction of an outbreak but are only an identification of a density level of early instars having the potential to increase to an outbreak level in a single generation. Whether or not rapid population growth takes place depends on survivorship of subsequent life stages in that generation and the early part of the next generation. Such general survey information is most valuable for alerting managers to potential outbreak situations so that they can make a more reliable prognosis from followup evaluations.

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# REARING THE WESTERN TUSSOCK MOTH ON ARTIFICIAL DIET WITH APPLICATION TO RELATED SPECIES

LINDA J. PETERSON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
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PORTLAND, OREGON

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## Introduction

Research investigations on the western tussock moth, *Orgyia cana* Edwards (Ferguson, 1978), require a continuous supply of large numbers of the insect in all life-cycle stages. To meet this need, the most effective method is laboratory rearing on an artificial diet; in this manner, the researcher has available a reliable source of uniform, healthy insects, independent of seasonal limitations imposed by availability of natural food.

Results of a study conducted to develop an artificial diet and a mass-rearing procedure for *O. cana* are reported here. The procedures are relatively simple, efficient, economical in materials and labor, and capable of yielding large numbers of healthy insects. The rearing program described in this report includes preparation of the artificial diet, rearing methods, evaluation of efficiency and effectiveness, and applicability of the techniques to similar insect species.

## Materials and Methods

### DIET COMPOSITION AND PREPARATION

The diet formula, modified from one described by Addy (1969), is given in table 1. The quantities indicated yield approximately 4 000 g of diet. Preparation of the diet is as follows: (1) the agar is dissolved in 2 800 ml distilled water; (2) this solution is autoclaved for 15 min at 15 psi; (3) the hot autoclaved mixture is allowed to cool to 65°C with periodic stirring; (4) all the dry ingredients except the sodium alginate, ascorbic acid, vitamin mixture, and the chlorotetracycline are stirred in; (5) this mixture is then blended for 4 min in a high-speed commercial blender; (6) the remaining ingredients are added and the entire mixture is blended for another 4 min; (7) the blended diet is immediately poured into a shallow stainless steel tray (58- x 58- x 1.25-cm)

Table 1--*Composition of the artificial diet for the western tussock moth*

| Ingredient | Amount |
|---|---|
| Water, distilled | 2 800.00 g |
| Agar, granulated | 62.00 g |
| Wheat germ, raw | 175.00 g |
| Casein, technical | 122.50 g |
| Sucrose | 122.50 g |
| Alphacel | 105.00 g |
| Cholesterol | 10.50 g |
| Sorbic acid | 4.25 g |
| Choline chloride | 3.50 g |
| Vitamin diet for insects[1] [2] | 50.00 g |
| Ascorbic acid (L) | 17.50 g |
| Sodium alginate | 17.50 g |
| Chlorotetracycline HCL | .30 g |
| Wheat germ oil, raw | 10.00 ml |

[1] ICN Pharmaceuticals, Inc.

[2] The use of trade, firm, or corporation names does not constitute an official endorsement by the U.S. Department of Agriculture.

and allowed to solidify; (8) the medium is then cut into 2.5- x 2.5-cm pieces for use--any diet not used immediately can be stored up to 7 days at 2°C.

## REARING METHODS

*Collection and Treatment of Eggs.*--Egg masses from laboratory rearings are maintained at ambient temperatures for approximately 30 days following oviposition prior to subjection to an obligatory cold treatment at 2°C and 45-percent RH for a minimum of 3 months. Following this cold treatment, the eggs are surface-sterilized in a 0.1-percent sodium hypochlorite solution (2 percent of a 5-percent commercial bleach preparation); this precautionary step eliminates the possibility of contamination by microbials or viruses (Getzin 1962). The sterilized eggs are held at 25°C and 45-percent RH with a 12-hr light-dark cycle; under this regime, eclosion occurs in 12-14 days.

*Handling and Feeding of Larvae.*--Newly hatched larvae (less than 24 hr in age) are transferred with a camel's-hair brush to disposable 15- x 100-mm petri dishes which serve as rearing containers (Lyon and Flake 1966). Ten larvae are placed in each dish, along with a piece of artificial medium; the dishes are then arranged in single layers on shallow rearing trays. For the larval feeding period the environmental conditions are maintained at 25°C, 45-percent RH, with a 12-hr photoperiod. The insects are refed every 7 days: the old medium is removed from the dish and is replaced with fresh diet. As 21-25 days are needed for larvae to reach pupation, a maximum of three refeedings is required.

*Collection and Sexing of Pupae.*--The newly developed pupae (less than 24-hr-old) are removed from the rearing dishes and sexed on a regular, daily basis; this grouping of pupae by age and sex is necessary in order to achieve optimum adult mating success, as well as to insure accuracy in experimental studies. Collection and sexing are accomplished with accuracy and efficiency by using an ordinary photographic light table and employing the following technique: individual rearing dishes are placed on the light table where the illumination from beneath permits the viewer to see into the newly spun cocoons and discern both the stage of pupal development and the sex. A smooth, dark, sclerotized shell characterizes a fully formed pupa. Male and female forms are easily distinguished on the basis of size and shape. The male pupa has a flattened anterior end, a narrow thorax, and an average length of 1.5 cm. The female pupa is considerably larger, averaging 2.3 cm in length with a pointed anterior end and a wide thorax. When the collected pupae are held under a regime of 25°C, 45% RH with a 9- to 12-hr photoperiod, adult emergence (male and female) occurs in 10 or 11 days.

*Mating and Oviposition of Adults.*--As soon as pupae are collected and sexed, those destined for use in propagation are set up in mating/oviposition containers. In this way, the need to handle adult moths is completely eliminated and emergence occurs in an unhampered manner. Preparation of the mating/oviposition container is as follows: female pupae (cocoons intact) are affixed to 6- x 8-in (15.2- x 20.3-cm) index cards with paper mucilage--20 females per card (fig 1). This card and 20-25 loose male pupae are placed inside a 5-lb Kraft paper bag (fig 2). The male pupae should be 24-48 hr older than female pupae; in this way, sexually mature males are available for mating with emerging females for optimum mating success. The mating/oviposition bag is stapled shut and set aside at 25°C, 45-percent RH, with an 8-hr photoperiod; no further handling is required until the egg masses are collected 30 days later.

*Figure 1.--Affixing female pupae in cocoons to a 6 X 8-in (15.2 X 20.3-cm) index card.*

*Figure 2.--Adding male pupae to a mating/oviposition bag containing card with female pupae in cocoons.*

## Results and Discussion

### *EFFECTIVENESS AND EFFICIENCY OF REARING PROGRAMS*

The artificial diet and procedures for the laboratory rearing of *O. cana* are successful in producing healthy insect specimens in all life-cycle stages. Results based on the rearing of five successive laboratory generations (averaging 4,000 larvae per generation) show the following: larvae develop rapidly and uniformly ($L_1$ to pupation averages 23 ± 2 days), pupae develop into adults at a consistent rate with a mortality of only 5 percent, adults emerge with no signs of wing or scale deformity and exhibit a mating success rate of 90 percent ± 5 percent, egg production per female is 250 ± 50 eggs, and eclosion from eggs held under optimum conditions (2°C, 45-percent RH for 3 months) is 90 percent ± 10 percent. As no loss of vigor or reproductive ability has been observed with five successive generations, indications are that the diet and methodology fully satisfy the nutritional, reproductive, and environmental needs of *O. cana*.

In addition, the rearing procedure for the western tussock moth represents an efficient and economical method of production. The uniform growth patterns and the consistently high survival rate at all stages of development permit efficient handling and keep materials and labor costs at a minimum. The techniques are also easily adjusted to meet varying research demands, ranging from small-scale stock maintenance to large-scale, mass-rearing programs.

### *APPLICATION TO OTHER SPECIES*

The diet and rearing techniques developed for the western tussock moth have yielded similar positive results when applied to certain related insect species. Currently, the Douglas-fir tussock moth, *O. pseudotsugata* (McDunnough) is being reared successfully in large numbers using the diet and procedures described. Overall success is comparable to that of *O. cana*; however, larval development time is extended by 7-10 days and optimum eclosion occurs after a more extensive cold treatment (4.5 mo at 2°C). In addition to *O. pseudotsugata*, the rusty tussock moth, *O. antiqua* (Linn.) and the white-marked tussock moth, *O. leucostigma* (J. E. Smith) respond well to this rearing program. While these latter species exhibit more variability in regard to optimum cold treatment duration and larval development time, healthy, vigorous insects with high survival and reproductive rates are produced. These results indicate that the diet and methodologies described for the western tussock moth have extensive application in rearing several species of the genus *Orgyia*.

## Conclusions

An artificial diet and a rearing method developed for the western tussock moth, *Orgyia cana* Edwards, provide an effective and efficient means of producing large numbers of healthy insects in the laboratory. The preparation of the artificial diet is relatively simple, and the diet formula provides adequate nutrition for the insect. In addition, the rearing methods devised for the handling of larvae, the collection and sexing of pupae, and the mating and oviposition of adults are simple techniques requiring minimal inputs of materials and labor. Together, the diet formula and the rearing techniques result in a high survival rate as well as uniform development of the insect in all life-cycle stages.

Of additional importance is the fact that the diet and procedures for rearing *O. cana* are applicable to other related species, including the Douglas-fir tussock moth and the rusty tussock moth.

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This paper describes an artificial diet and a rearing procedure for the western tussock moth, *Orgyia oma* Edwards. The diet and rearing regime permit laboratory production of successive generations of the species with continued maintenance of insect vigor and reproductive capability. The diet and rearing techniques are also applicable to other species including the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), and the rusty tussock moth, *O. antiqua* (Linn.).

KEYWORDS: Insect rearing, artificial diet, tussock moth (western), *Orgyia oma*, tussock moth (Douglas-fir), *Orgyia pseudotsugata*, tussock moth (rusty), *Orgyia antiqua*.

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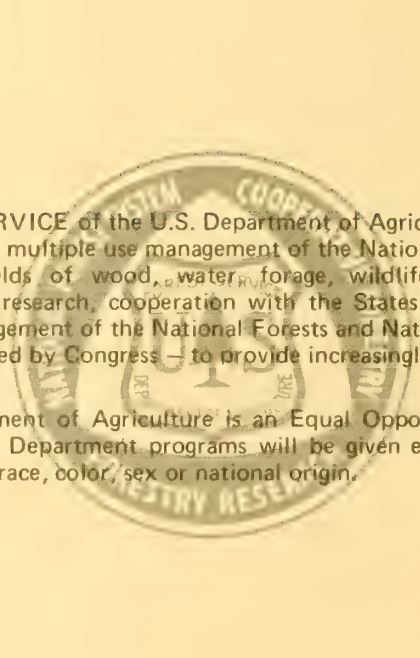

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USDA FOREST SERVICE RESEARCH PAPER PNW-240

Paul E. Aho

Lewis F. Roth

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# DEFECT ESTIMATION FOR WHITE FIR IN THE ROGUE RIVER NATIONAL FOREST

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
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## *METRIC CONVERSIONS*

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 yard = 0.914 meter
1 cubic foot = 28 316.85 cubic centimeters
1 board foot = 0.0024 cubic meter

# DEFECT ESTIMATION FOR WHITE FIR IN THE ROGUE RIVER NATIONAL FOREST

*Reference Abstract*

Aho, Paul E., and Lewis F. Roth.
1978. Defect estimation for white fir in the Rogue River National Forest. USDA For. Serv. Res. Pap. PNW-240, 18 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A total of 501 white firs with and without indicators of defect were felled, dissected, and studied in 53 widely scattered localities in the Rogue River National Forest. Two methods for estimating defect in white firs are given: (1) Defect percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes are tabulated by d.b.h. and age; defect percentages are added for various indicators. (2) Average length deductions below and above indicators plus flat factors for hidden defect are presented. Multiple regression equations, used to derive the indicator defect percentage tables, are given. Equations excluding age as a variable are included for use when age is unknown. Procedures for developing the estimating equations and testing their precision are discussed.

KEYWORDS: Defect deduction (-merchantable volume, white fir, *Abies concolor*, Indian paint fungus, *Echinodontium tinctorium*, Oregon (Rogue River National Forest).

*RESEARCH SUMMARY*

*Research Paper PNW-240*

*1978*

Two methods were developed for estimating the extent of defect in standing white fir trees in southwestern Oregon:

1. Defect percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes are tabulated by d.b.h. and age. When indicators are present, constant defect percentages must be added. Multiple regression equations, used to derive the indicator defect percentage tables, are given. Equations excluding age as a variable are included for use when age is unknown.

2. Length deductions based on average extent of defect below and above various indicators are given along with flat percentage factors for hidden defect.

The first method was considered the most accurate and least subjective. It was determined statistically that a "common" equation for each cubic- and board-foot volume measure could be used to estimate defect in white firs throughout the Rogue River National Forest. The estimating equations were tested for accuracy on an independent sample of trees and were found to predict defect volumes within accepted standards. The first method, defect estimating equations, can be most useful in large scale inventory cruises since it is less subjective and the equations can be used in computer programs compiling inventory data. The second method, average length deductions, may be effectively used by experienced cruisers in timber sale areas.

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# INTRODUCTION

The Rogue River National Forest lies on the western slopes of the Cascade Range and on the northern slopes of the Siskiyou Mountains in southwestern Oregon. Total area of the Forest is slightly more than 620,000 acres. Commercial volume of all tree species is estimated to be 3,209 million cubic feet. This timber provides approximately one-third of the raw material for the wood-using industries of the surrounding area. Among 21 species, white fir (*Abies concolor* (Gord. and Glend.) Lindl. accounts for 20 percent of the board-foot volume and 23 percent of the growing stock on this Forest.

White fir is an important component of three timber zones in southwestern Oregon: (1) the Mixed Conifer Zone (various pines, incense-cedar (*Libocedrus decurrens* Torr.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*)) at elevations between 2,000 and 3,500 feet; (2) the White Fir Zone where it occurs in relatively pure stands or in association with Douglas-fir at middle elevations between 2,500 and 4,000 feet; and (3) the Red Fir Zone (*A. magnifica* Murr. var. *shastensis* Lemm.) at elevations between 3,500 and 6,000 feet where it is often the most important associated species (Franklin and Dyrness 1973).

Little cutting occurred in these white fir stands before 1960 because of inaccessibility and excessive defect. Improved markets for white fir have been developed through limited supply of more popular species. More roads have made the white fir available, but increased utilization has not been without problems. Many stands are overmature and defective because of heart rot which weakens trees mechanically, destroys wood volume, and reduces tree vitality. Decay of usable wood, however, is the greatest loss.

Accurate methods for estimating defect in standing white firs are needed for preparation of forest inventories and timber sales. Estimates of gross volume usually are satisfactory, but estimates of net figures are poor because of indadequate allowances for defect (Bruce and Cowlin 1968). Closer utilization of defective stands can be achieved through knowledge of the extent and distribution of decay. Trees with cull can be bucked more accurately and timber sales can be scheduled based on amount of defect in stands.

This paper presents two methods for estimating the extent of defect in living white firs in the Rogue River National Forest, describes the procedure used to develop the most reliable of the two defect-estimating methods, and presents a measure of the precision of the estimating technique when applied to an independent timber sample.

# STUDY METHODS

## Field Procedure

### SAMPLE TREE SELECTION

The study included 501 trees selected in 53 localities in the Rogue River National Forest (table 1, fig. 1). To better study the large and heterogeneous area to which results must apply, we stratified samples among the three broad forest zones previously stated. Areas previously identified on maps by forest personnel as representative of the low elevation mixed conifer, middle elevation white fir, and higher elevation Shasta red fir zones were sampled. In various stands in each zone, an attempt was made to obtain a representative sample of trees with and without defect indicators, including as complete a representation of tree ages and diameters as possible. Appropriate defect indicators for white fir were determined from a preliminary study by Aho in 1966.[1/] These include: sporophores (conks) of *Echinodontium tinctorium* Ell. and Ev. and *Phellinus pini* var. *cancriformans* Larsen, Lomb. & Aho, nom. ined.,[2/] basal and trunk injuries, frost cracks, dead and broken tops, forks, crooks, dead vertical branches, and mistletoe cankers. Normally, trees with at least one indicator were selected from a stand, along with comparable trees without indicators. For various reasons, trees in some age and size classes with specific indicators were difficult to find. This was especially true in the lower elevation Mixed Conifer Zone (table 1).

Table 1--*Number of study trees with defect indicators by forest zone*

| Forest zone | Study sample | |
|---|---|---|
| | Localities | Trees |
| Mixed Conifer | 8 | 72 |
| White Fir | 22 | 216 |
| Shasta Red Fir | 23 | 213 |
| Total | 53 | 501 |

[1/] Aho, Paul E. 1968. A progress report on defect in white and red firs on the Rogue River National Forest. 20 p. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

[2/] The new variety is planned for publication elsewhere.

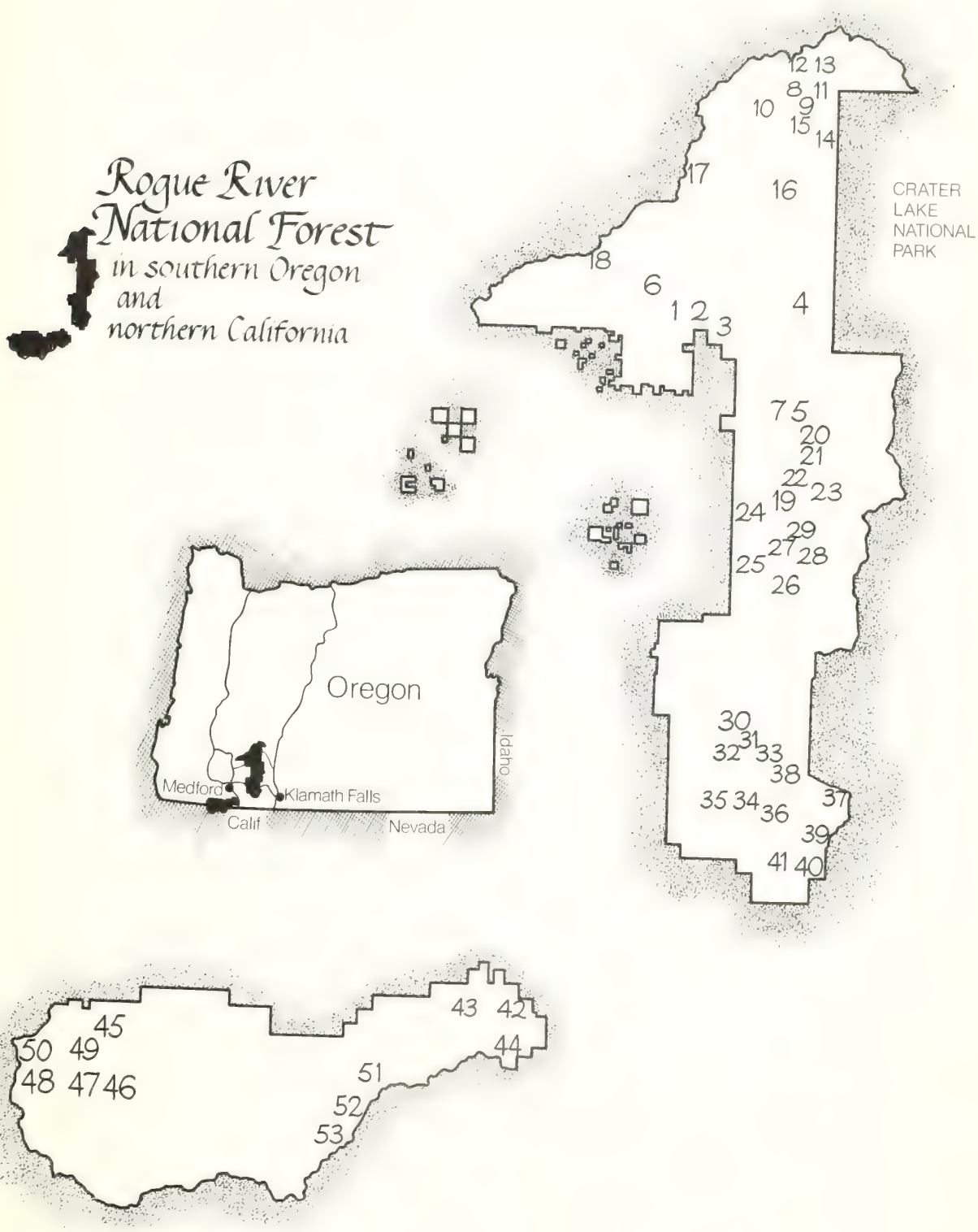


*Figure 1.--Map of area where investigations were conducted. Numbers indicate study localities.*

### SAMPLE TREE DISSECTION

The following information was recorded for indicators of defect: type, height from the ground to the bottom of the indicator, and when appropriate for a given indicator, its length, width, depth, diameter, aspect on the tree, position, condition, and age. For cubic volumes, all trees were felled and dissected at 16.3-foot intervals from a 1-foot stump to a 4-inch top d.i.b. (diameter inside bark); they were measured at breast height (d.b.h.) and at the midpoint of the first 16-foot log. Board-foot volumes of trees 11-inch d.b.h. and larger were measured to a variable merchantable top diameter (40 percent of d.b.h., d.i.b.). Other cuts were made so that decay, shake, check, and frost cracks or forks could be measured, infection courts located, and wounds aged. Tree age was determined by a count of rings at stump height.

## *Office Procedure*

### CALCULATION OF TREE AND DEFECT VOLUMES

Basic volumes were calculated by an automatic data processing system using a program which computed cubic-foot volumes of logs and decay columns by the Smalian formula. No arbitrary cull rules were used in cubic volume measurement. Board-foot volumes of logs were calculated by the Scribner and International 1/4-inch log scales. Deductions for decay, shake, check, and frost cracks in board feet were made by the squared-defect method. The squared-defect deduction formulas (reduced form) for each log scale were taken from the National Forest Log Scaling Handbook (USDA Forest Service 1964).

### DERIVATION AND TESTING OF DEFECT ESTIMATING EQUATIONS

The following procedures were used to generate and test defect estimating formulas:

1. The best estimating variables were determined by multiple regression analysis. Eleven independent and three dependent variables (table 2) were tested in a regression (REX) program which screened all combinations of independent variables to find the "best" regression, i.e., the one with the smallest relative mean-squared-residual (Grosenbaugh 1967, p. 7).

All 501 study trees were used to determine the best combination of variables when the dependent variable was cubic-foot defect percent, but only trees (463) larger than 11-inch d.b.h. were used for analysis of Scribner and International board-foot volumes. The best independent variables for each dependent variable are listed in table 3. Since "forks" was selected as a variable only in the International board-foot estimating equation and its impact on estimates

Table 2--*Number of indicators on 501 white fir trees from three forest zones* [1/]

| Indicators | Mixed Conifer Zone | White Fir Zone | Shasta Red Fir Zone | All types |
|---|---|---|---|---|
| None | 10 | 27 | 38 | 75 |
| *Echinodontium tinctorium* conks | 16 | 50 | 53 | 119 |
| *Phellinus pini* var. *cancriformans* conks or cankers | 12 | 32 | 11 | 55 |
| Basal injuries | 26 | 49 | 38 | 113 |
| Frost cracks | 25 | 61 | 77 | 163 |
| Trunk injuries | 9 | 29 | 18 | 56 |
| Broken tops | 5 | 22 | 36 | 63 |
| Dead tops | 4 | 11 | 8 | 23 |
| Crooks | 9 | 32 | 42 | 83 |
| Forks | 5 | 22 | 34 | 61 |
| Mistletoe trunk cankers | 5 | 16 | 7 | 28 |
| Dead vertical branches | 2 | 5 | 13 | 20 |

[1/] Many trees had more than one kind of indicator.

Table 3--*Combinations of independent variables (indicators) giving the smallest relative mean squared residual with each dependent variable tested in multivariate regression analysis*

| Independent variables | Dependent variables[1/] | | |
|---|---|---|---|
| | Cubic-foot defect percent | Board-foot defect percent | |
| | | Scribner | International |
| Tree d.b.h. | X | X | X |
| Tree age | X | X | X |
| *Echinodontium tinctorium* conks | X | X | X |
| *Phellinus pini* var. *cancriformans* conks or cankers | X | X | X |
| Basal injuries | X | X | X |
| Frost cracks | -- | X | X |
| Trunk injuries | X | X | X |
| Broken or dead tops | X | -- | -- |
| Crooks | X | -- | -- |
| Forks | X | -- | X |
| Mistletoe cankers | -- | -- | -- |
| Dead vertical branches | -- | -- | -- |

[1/] X's indicate independent variables that can be used with each dependent variable to get the "best" regression estimating equations. Dashes indicate the variables having little or no effect in increasing precision of the estimating equations.

of decay percents was so small, it was deleted.

2. From only the best variables, estimating equations were calculated for each forest zone. The equations for each volume measurement for the three zones were tested by covariance analysis (RECOR) for differences among equations.[3/] Significant differences were not found for either board-foot measurement. There were no significant differences among regression surfaces or elevations; thus, "common" equations were selected for each board-foot measure to make defect estimates in all forest zones (Snedecor and Cochran 1967, chapter 14).

Regression surfaces among cubic-foot estimating equations for each forest zone were significantly different at the 5-percent level of probability; however, because the statistical evidence of differences in estimating equations was slight and since there is a practical problem of identifying forest zones in the field, a "common" equation was selected for use in cubic volume defect estimations also.

3. The common estimating equations for each volume measurement were tested on an independent sample of 146 white firs felled, dissected, and measured in 1966 (see footnote 1, page 2) by the methods used in the present study. Estimated defect percents calculated for each of those 146 trees by the equations developed here were compared with those measured for each tree in 1966 by chi-square (Freese 1960). An index of accuracy of 15 percent was chosen for the cubic-foot test and 25 percent for the board-foot. The test of differences between actual and estimated defect percents at the 5-percent probability level was met for each volume measurement.

The intent of defect prediction schemes is to accurately determine net volume of a sample of trees by estimating the total sound volume of individual trees. To see if the equations satisfied this criterion, we computed estimated cubic- and board-foot defect volumes for the 1966 sample trees by applying the estimated defect percents to tree volumes. Estimated defect volumes for trees were totaled, converted to percents of total merchantable volumes of the sample trees, and compared with the measured (actual) defect volumes. Estimated defect in cubic- and board-foot volumes was within 1 percent of the actual defect for the entire sample. Since accepted standards of precision for determining net volumes of cruise trees is 5 to 10 percent (Bruce and Cowlin 1968), the estimating equations acceptably predicted defect volume in this sample and thus provide further support for use of common equations wherever white fir occurs in the Rogue River National Forest.

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[3/] Pacific Northwest Forest and Range Experiment Station. 1970. Program RECOR. Library of Computer Programs, Portland, Oreg.

## DEFINITION AND DESCRIPTION OF DEFECT AND INDICATORS

*Defect*.--When expressed as cubic volume, defect includes only decay; for board-foot deductions defect includes decay, shake, check, and frost cracks. Crook, sweep, breakage in felling, and missing parts of trees, such as broken tops, are not deducted in either measurement.

*Defect percentages*.--Deductions include the appropriate defect within the tree from a 1-foot stump height to a 4-inch top d.i.b. for cubic volume, and to the point where stem diameter inside bark equals 40 percent of tree d.b.h. for Scribner and International board-foot volumes. No arbitrary log cull rules were used in deductions for cubic-foot defect. In board feet, a log was considered totally defective if it was less than one-third sound.

*Defect indicators*.--These are of two general types: (1) signs of decay fungi, such as conks or punky knots, and (2) wounds or scars indicating possible infection courts for decay fungi. These include basal and trunk injuries, frost cracks, crooks, forks, mistletoe cankers, dead and broken tops, and dead vertical branches. Frost cracks are board-foot defects even if they are not associated with decay.

*Conks*.--These are certain signs of decay. The only fungi found consistently producing sporophores on white firs in this study were *Echinodontium tinctorium* and *Phellinus pini* var. *cancriformans*. *Echinodontium tinctorium* sporophores (fig. 2) were the most significant defect indicators because considerable defect usually is associated with them (fig. 3).

*Figure 2.--Conks of the Indian paint fungus,* Echinodontium tinctorium *on white fir.*

*Figure 3.--Sections of a white fir tree at 32, 49, 65, 81, and 98 feet illustrate extent of* Echinodontium tinctorium *decay.*

They are generally seen protruding from the trunk at the base of branch stubs (fig. 2); but they may be attached at the junction of live branches as well and may be overlooked in the living crown.

On thin-barked host species, *P. pini* var. *cancriformans* invades the sapwood from the heartwood and often locally kills the cambium, thereby causing cankered areas (fig. 4). This behavior is particularly common in true firs. Sporophores often are profusely scattered over the canker surface (fig. 5). Occasionally cankers are caused when no conks are present (fig. 6). Defect deductions for these cankers

*Figure 4.--Decay and cankers caused by* Phellinus pini *var.* cancriformans.

*Figure 5.--*Phellinus pini *var.* cancriformans *conks on a canker at the base of a white fir.*

*Figure 6.--*Phellinus pini *var.* cancriformans *caused canker without conks.*

are the same as for cankers with sporophores.

At certain times of the year, *Pholiota* sp. and *Hericium abietis* (Weir ex Hubert) K. Harrison may produce sporophores on or near injuries. Deductions for these should be based on the type of injury rather than on the sporophores.

*Basal injuries*.--These include open or closed wounds in contact with the ground. Basal scars may be caused by fires (fig. 7), falling trees, or other mechanical injuries and are one of the most important defect indicators. They are sometimes inconspicuous and easily overlooked, resulting in significant error in volume estimates. With the exception of frost cracks, recent injuries (basal and trunk wounds and dead and broken tops less than 10 years old) should be ignored since little or no defect is associated with them.

*Figure 7.--A basal fire injury on a white fir.*

*Trunk injuries*.--They include open or closed wounds more than 1 foot long and more than 10 years old which are located below the merchantable top diameter but are not in contact with the ground (fig.8).

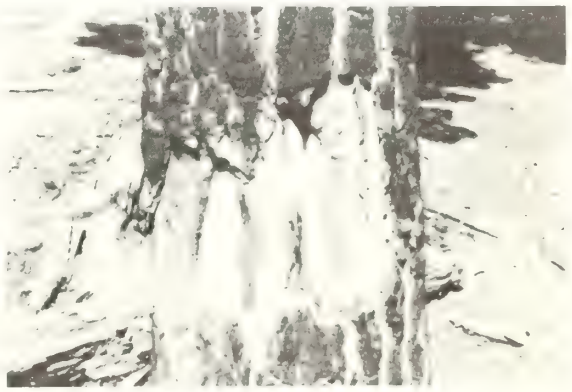

*Figure 8.--A trunk injury on a white fir probably caused by a falling tree.*

Trunk injuries include wounds from falling trees, lightning, animal damage, and logging.

*Frost cracks*.--These open scars or seams are probably caused by freezing (fig. 9). They are particularly common in white firs and probably are associated with excessive moisture (wetwood). Often, trees with bleeding cracks will also bear Indian paint fungus conks higher on their trunks. The decay associated with the conks will not usually extend into the wetwood and frost crack area. Frost cracks, shake, and wetwood occur together (fig. 10). Trees with frost cracks

*Figure 9.--A basal frost crack in a white fir.*

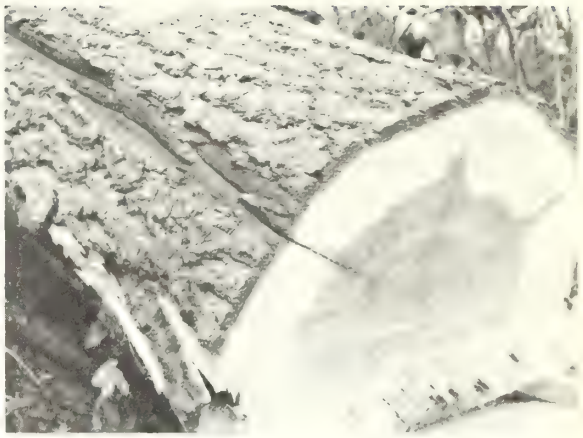

*Figure 10.--Cross-section at the base of a white fir showing wetwood, frost cracks, and shake.*

as their only defect indicator generally do not have decay associated with the cracks; thus, there is no cubic volume loss. There will be board-foot defect, however, because of the cracks, check, and shake.

*Top injuries*.--Included are tops broken by wind, ice, or snow (fig. 11) within the merchantable portion of the tree and spike tops resulting from insects, rust fungi, dwarf mistletoe, animals, or unknown causes (fig. 12). Tops that

*Figure 11.--A white fir with a broken top within the merchantable portion of the bole.*

*Figure 12.--A white fir with a dead top caused by bark beetles.*

are dead or are broken above the merchantable limit and recent top damage are not defect indicators.

*Crooks*.--These are sudden bends in the merchantable bole. They may result when young trees bend under ice, snow, or animals; in older trees, they may result from breaks or leader death high in the tree. The former, since there is no break, are free of decay whereas the latter often become infected (fig. 13). If the diameter at the crook is less than about 10 inches, the decay will usually extend downward only.

*Forks*.--Forked trees result when two or more lateral branches succeed in replacing a dead or broken leader (fig. 14).

*Figure 13.--A white fir with a crook or "pistol butt" near the ground. An old, broken-off leader usually indicates that decay is present.*

*Figure 14.--A forked white fir.*

*Dead vertical branches*.--These may be old leaders or lateral branches that died after unsuccessful competition with a stronger leader (fig. 15). When dead vertical branches are associated with a crook, decay is usually present.

*Dwarf mistletoe infection*.--*Arceuthobium abietinum* Engelm. ex Munz f. sp. *concoloris* Hawksworth & Wiens often results in pronounced swellings or cankers on the bole or large branches (fig. 16). Cankers with tight bark (fig. 16) usually do not admit decay fungi. When the bark on these cankers sloughs off, exposing wood (fig. 17), infection by decay fungi can occur; however, decay generally does not extend beyond the limits of the swelling.

*Figure 15.--A dead vertical branch on a white fir. If a crook occurs, decay is usually present.*

*Figure 16.--A dwarf mistletoe trunk canker on a white fir. The bark is still tight; thus, there will be no associated decay.*

*Figure 17.--Open dwarf mistletoe trunk canker on a white fir. Decay may be associated with these indicators, but it seldom extends beyond the limits of the swelling.*

# ESTIMATION OF DEFECT IN WHITE FIR

Two methods are presented here for estimating the extent of defect in standing white fir trees in the Rogue River National Forest, and they may be applicable in all of southwestern Oregon:

1. Indicator defect factors, developed by multiple regression analysis, are given as percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes.

2. Average deductions for length below and above indicators are presented along with flat percentage factors for hidden defect.

Although both types of defect factors may be fairly accurate with small samples, or even single trees, results will be more accurate when the factors are applied to larger numbers of trees. The two methods cannot be used together in a given timber cruise.

## *Indicator-Defect Percentage Factors*

Defect percentages can be calculated from table 4 (Scribner), table 5 (International), and table 6 (cubic).

Table 4--*Defect in percent*[1/] *of gross merchantable Scribner board-foot volume from a 1-foot stump height to a variable (Girard) top d.i.b. for white fir trees by age and d.b.h.*[2/]

| D.b.h. (inches) | Tree age (years) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
| 11 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 |
| 12 | 2 | 4 | 6 | 8 | 10 | 12 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 38 |
| 13 | 1 | 3 | 5 | 7 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 31 | 33 | 35 | 37 |
| 14 | 0 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 26 | 28 | 30 | 32 | 34 | 36 |
| 15 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 |
| 16 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 |
| 17 | 0 | 0 | 2 | 4 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 30 | 32 | 34 |
| 18 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 23 | 25 | 27 | 29 | 31 | 33 |
| 19 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| 20 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 |
| 21 | 0 | 0 | 0 | 1 | 3 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 29 | 31 |
| 22 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 22 | 24 | 26 | 28 | 30 |
| 23 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 19 | 21 | 23 | 25 | 27 | 29 |
| 24 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| 25 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 26 | 28 |
| 26 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 21 | 23 | 25 | 27 |
| 27 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 18 | 20 | 22 | 24 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 13 | 15 | 17 | 19 | 21 | 23 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 19 | 21 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 10 | 12 | 14 | 16 | 18 | 20 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 9 | 11 | 13 | 15 | 17 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |

[1/] These constant defect percentages must be added for each type of indicator present on a sample tree: *Echinodontium tinctorium* conks, 49; *Phellinus pini* var. *[illegible]* conks or cankers, 21; basal injuries, 8; trunk injuries, 7; and frost cracks, 6.

[2/] Derived by the common equation: $P_b = 4.886 + 0.105A - 0.765 + 4.395C + 21.456D + 21.904E + 7.403F + 6.047G$, where: $P_b$ = percent of gross merchantable Scribner board-foot volume that is cull; A = tree age in years; B = tree d.b.h. in inches; C = 1 if one or more *Echinodontium tinctorium* conks are present, 0 if no conks; D = 1 if one or more *Phellinus pini* var. *[illegible]* conks or cankers are present, 0 if no conks or cankers; E = 1 if one or more basal injuries are present, 0 if no basal injuries; F = 1 if one or more trunk injuries are present, 0 if no trunk injuries; G = 1 if one or more frost cracks are present, 0 if no frost cracks.

The coefficient of determination ($R^2$) for this equation is 0.645.

Table 5--*Defect in percent*[1/] *of gross merchantable International board-foot volume from a 1-foot stump height to a variable (Girard) top d.i.b. for white fir trees by age and d.b.h.*[2/]

| D.b.h. (inches) | Tree age (years) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
| 11 | 1 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 34 | 36 | 38 |
| 12 | 1 | 3 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 29 | 31 | 33 | 35 | 37 |
| 13 | 0 | 2 | 4 | 6 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 24 | 26 | 28 | 30 | 32 | 34 | 36 |
| 14 | 0 | 1 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 34 | 36 |
| 15 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 29 | 31 | 33 | 35 |
| 16 | 0 | 0 | 2 | 4 | 6 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 24 | 26 | 28 | 30 | 32 | 34 |
| 17 | 0 | 0 | 1 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 34 |
| 18 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 31 | 33 |
| 19 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 26 | 28 | 30 | 32 |
| 20 | 0 | 0 | 0 | 1 | 3 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 21 | 23 | 25 | 27 | 29 | 31 |
| 21 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 31 |
| 22 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 26 | 28 | 30 |
| 23 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 21 | 23 | 25 | 27 | 29 |
| 24 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| 25 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 26 | 28 |
| 26 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 21 | 23 | 25 | 27 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 18 | 20 | 22 | 24 | 26 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 13 | 15 | 17 | 19 | 21 | 23 | 25 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 23 | 25 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 18 | 20 | 22 | 24 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 13 | 15 | 17 | 19 | 21 | 23 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 23 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 18 | 20 | 22 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 13 | 15 | 17 | 19 | 21 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 10 | 12 | 14 | 16 | 18 | 20 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 20 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 15 | 17 | 19 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 10 | 12 | 14 | 16 | 18 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 7 | 9 | 11 | 13 | 15 | 17 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 15 | 17 |

[1/] These constant defect percentages must be added for each type of indicator present on a sample tree: *Echinodontium tinctorium* conks, 46; *Phellinus pini* var. *canariformans* conks or cankers, 20; basal injuries, 21; trunk injuries, 7; and frost cracks, 6.

[2/] Derived by the common equation: $P_b = 3.104 + 0.107A - 0.731B + 46.435C + 19.810D + 20.898E + 6.776F + 5.747G$;
where: $P_b$ = percent of gross merchantable International board-foot volume that is cull; A = tree age in years; B = tree d.b.h. in inches; C = 1 if one or more *Echinodontium tinctorium* conks are present, 0 if no conks; D = 1 if one or more *Phellinus pini* var. *canariformans* conks or cankers are present, 0 if no conks or cankers; E = 1 if one or more basal injuries are present, 0 if no basal injuries; F = 1 if one or more trunk injuries are present, 0 if no trunk injuries; G = 1 if one or more frost cracks are present, 0 if no frost cracks.

The coefficient of determination ($R^2$) for this equation is 0.629.

Table 6--*Defect in percent*[1/] *of gross merchantable cubic-foot volume from a 1-foot stump height to a 4-inch top d.i.b. for white fir trees by age and d.b.h.*[2/]

| D.b.h. (inches) | Tree age (years) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
| 5 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 16 |
| 6 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 14 | 15 | 16 |
| 7 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12 | 13 | 14 | 15 | 16 |
| 8 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 9 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 14 | 15 |
| 10 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 11 | 12 | 13 | 14 | 15 |
| 11 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 12 | 0 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 13 | 14 |
| 13 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 11 | 12 | 13 | 14 |
| 14 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9 | 10 | 11 | 12 | 13 | 14 |
| 15 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 13 |
| 16 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 10 | 11 | 12 | 13 |
| 17 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 |
| 18 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12 |
| 19 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 10 | 11 | 12 |
| 20 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 |
| 21 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 22 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9 | 10 | 11 |
| 23 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 | 8 | 9 | 10 | 11 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9 | 10 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 | 8 | 9 | 10 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 9 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 | 9 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 6 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 |

[1/] These constant defect percentages must be added for each type of indicator present on a sample tree: *Echinodontium tinctorium* conks, 26; *Phellinus pini* var. *canariformans* conks or cankers, 10; basal injuries, 9; trunk injuries, 4; crooks, 2; forks, 1; and dead or broken tops, 2.

[2/] Derived by the common equation: $P_c = 0.837 + 0.043A - 0.311B + 25.518C + 9.876D + 9.175E + 4.221F + 2.108G + 1.238H + 2.3901$;
where: $P_c$ = percent of gross merchantable cubic-foot volume that is cull; A = tree age in years; B = tree d.b.h. in inches; C = 1 if one or more *Echinodontium tinctorium* conks are present, 0 if no conks; D = 1 if one or more *Phellinus pini* var. *canariformans* conks or cankers are present, 0 if no conks or cankers; E = 1 if one or more basal injuries are present, 0 if no basal injuries; F = 1 if one or more trunk injuries are present, 0 if no trunk injuries; G = 1 if one or more dead or broken tops are present, 0 if no dead or broken tops; H = 1 if one or more forks are present, 0 if no forks; I = 1 if one or more crooks are present, 0 if no crooks.

The coefficient of determination ($R^2$) for this equation is 0.617.

Volume defect factors were derived from the common (weighted average of the estimating equations for the three forest cover types) equations footnoted in tables 4-6. For ease in presentation, the equations were solved and tabulated for d.b.h. and age only. Constants are included to be added for each type of defect indicator present (tables 4-6). Equations without tree age as a variable are included in table 7 for use when ages are not available.

Table 7--*Coefficients of regression equations*[1/] *for estimating cubic- and board-foot defect percents in individual white fir*

| Volume measure | Number of trees | Regression coefficients for independent variables[2/] | | | | | | | | | Y-intercept | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | | |
| Cubic feet | 501 | -0.172 | 26.711 | 8.977 | 9.478 | 3.810 | -- | 2.346 | 1.191 | 2.020 | 5.399 | 0.598 |
| Board feet, Scribner rule | 463 | -.416 | 52.428 | 19.350 | 22.600 | 6.476 | 6.382 | -- | -- | -- | 15.459 | .617 |
| Board feet, International 1/4-inch rule | 463 | -.374 | 49.540 | 17.655 | 21.610 | 5.823 | 6.039 | -- | -- | -- | 13.929 | 597 |

[1/] Based on the weighted average of equations for trees from the three white fir forest cover types.

[2/] $X_1$ = tree d.b.h. in inches.
$X_2$ = 1 if one or more *Echinodontium tinctorium* conks present;
0 if no conks present.
$X_3$ = 1 if one or more *Phellinus pini* var. *cancriformans* cankers or conks present;
0 if no cankers or conks present.
$X_4$ = 1 if one or more basal injuries more than 10 years old present;
0 if no basal injuries present.
$X_5$ = 1 if one or more trunk injuries more than 10 years old and longer than 1 foot present;
0 if no trunk injuries present.
$X_6$ = 1 if one or more frost cracks present;
0 if no frost cracks present.
$X_7$ = 1 if dead or broken top present;
0 if no dead or broken top present.
$X_8$ = 1 if one or more forks present;
0 if no forks present.
$X_9$ = 1 if one or more crooks present;
0 if no crooks present.
$R^2$ = Coefficient of determination or the percent of variation explained by the variables in the equations.

Solving the equations for some combinations of d.b.h., age, and indicators for a tree can result in defect percentages of less than zero or greater than 100 percent. In these cases, if the equations are used in a computer program, the program should set the percentages at zero or 100 percent.

## APPLICATION OF DEFECT PERCENTAGE FACTORS

Accurate application of defect percentages in tables 4 to 6 requires familiarity both with the definitions of cubic- and board-foot defect and with which indicators are reliably associated with each type of volume measurement. Sample trees must be carefully examined, the presence of meaningful indicators noted, and d.b.h. and age measured. When age is not known, the appropriate equation in table 7 can be used to calculate defect percent.

A 16-inch, 140-year-old white fir without indicators would have defect deductions of 7 percent of its gross merchantable Scribner board-foot volume (table 4), 6 percent of its International board-foot volume (table 5), and 2 percent of its cubic-foot volume (table 6). If, in addition, the tree has an *E. tinctorium* conk, the following constants for this indicator must be added to the defect percents to obtain the proper deduction: 26 percent for cubic-foot volume, 49 percent for Scribner board-foot volume, and 46 percent for International board-foot volume. Thus, the total defect percents for the above tree would be 28, 56, and 52 percent for cubic volume and for Scribner and

International board-foot volumes, respectively. If other defect indicators were present, additional appropriate constants would be necessary to obtain the full deduction for the tree.

### *Indicator Length Deductions and Flat Percentage Factors For Hidden Defect*

It is customary in certain types of timber cruises to determine net tree volumes by deducting portions of trees below and above visible indications of defect. Therefore, average length deductions are presented for the more reliable indicators on white fir (table 8). In many instances, decay columns ran into the roots, into another decay column in the bole, or into a missing top. Because of such interference, some decay columns were unusable in determining average length deductions (note difference between the number of trees with indicators and the number of indicators used to determine average deductions in table 8).

Table 8--*Length deductions for the more reliable indicators of defect on white firs in the Rogue River National Forest*

| Type of indicator | Trees with indicators | Data for deduction below bottom of indicator | | | | Data for deduction above top of indicator | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Average length of deduction | Indicators used to compute average[1/] | Range | Indicators without deductions[2/] | Average length of deduction | Indicators used to compute average[1/] | Range | Indicators without deductions[2/] |
| | Number | Feet | Number | Feet | Number | Feet | Number | Feet | Number |
| *Echinodontium tinctorium* conks | 119 | 11 | 91 | 0-60 | 1 | 20 | 111 | 0-80 | 1 |
| *Phellinus pini* var. *cancriformans* conks or cankers | 55 | 4 | 27 | 0-14 | 9 | 6 | 46 | 0-28 | 14 |
| Basal injuries more than 10 years old | 105 | -- | -- | -- | -- | 9 | 94 | 0-48 | 42 |
| Trunk injuries more than 10 years old and 1 foot long | 53 | 1 | 46 | 0-9 | 36 | 2 | 50 | 0-17 | 40 |
| Crooks | 82 | 2 | 74 | 0-19 | 57 | 1 | 74 | 0-11 | 67 |
| Forks | 60 | 1 | 57 | 0-12 | 41 | 2 | 54 | 0-25 | 49 |
| Top injuries more than 10 years old | 85 | 3 | 83 | 0-18 | 35 | -- | -- | -- | -- |

[1/] Does not include indicators with decay columns that ran into decay columns associated with other indicators nor those that ran into the ground or a missing top.

[2/] Number of indicators that had either no associated defect or such a small amount that no deduction was necessary. Many basal and trunk injuries, for instance, had considerable volumes of defect within the limits of the injuries, but little or none below or above.

The range of length deductions for a given indicator varies considerably. For instance, length deductions below and above *E. tinctorium* conks varied from 0 to 60 feet below the lowest conks and 0 to 80 feet above the highest (table 8). Moreover, except for *E. tinctorium* conks, many of each indicator type had no associated defect (table 8). Therefore, the average deduction for a given indicator class should be applied to each individual of that class encountered.

## APPLICATION OF LENGTH DEDUCTIONS AND FLAT PERCENTAGE FACTORS FOR HIDDEN DEFECT

Length deductions in table 8 are only for the more reliable indicators of defect in white firs. Again, as with

the defect percentages, length deductions are averages, so they cannot be expected to be accurate for individual trees or even small groups of trees. The minimum number of trees needed for accurate defect volume estimates has not been determined; it will vary from area to area because the percentage of trees with certain types of indicators will also vary.

Application of the length deductions is relatively easy. If a tree has a series of *E. tinctorium* conks and a broken top, deduct the portion of the tree 11 feet below the lowest conk to 20 feet above the highest and the 3 feet below the broken top (table 8). Where there are two or more different indicators in one segment of the tree, use the indicator with the longest length deduction. For instance, if there is a crook within a series of *E. tinctorium* conks, ignore the crook and base the deduction on the sporophores.

Total net cubic-foot and Scribner and International board-foot volumes must be reduced by 0.4, 5.2, and 4.2 percent, respectively, to account for hidden defect (table 9).

Table 9--*Cubic- and board-foot hidden defect percentages by d.b.h. classes for white fir on the Rogue River National Forest*[1/]

| D.b.h. class | Basis | Average d.b.h. | Average age | Hidden defect percentages | | |
|---|---|---|---|---|---|---|
| | | | | Cubic feet | Board feet | |
| | | | | | Scribner rule | International 1/4-inch rule |
| Inches | Number | Inches | Years | Percent | | |
| 5.0-10.9 | 38 | 8.5 | 141 | 0.2 | -- | -- |
| 11.0-14.9 | 38 | 13.2 | 158 | .5 | 2.9 | 2.6 |
| 15.0-18.9 | 94 | 17.1 | 164 | .4 | 4.1 | 3.5 |
| 19.0-22.9 | 86 | 20.9 | 179 | .9 | 5.9 | 4.9 |
| 23.0-26.9 | 77 | 24.7 | 185 | .3 | 4.4 | 3.6 |
| 27.0-30.9 | 87 | 29.0 | 196 | .1 | 4.4 | 3.8 |
| 31.0-34.9 | 44 | 32.7 | 225 | .2 | 3.6 | 2.8 |
| 35.0-38.9 | 19 | 37.0 | 223 | 1.2 | 12.3 | 9.5 |
| 39.0+ | 18 | 41.7 | 269 | .8 | 5.6 | 4.7 |
| Total or average | 501 | 23.0 | 185 | .4 | 5.2 | 4.2 |

[1/] Hidden defect percentages in this table should be used only with indicator length deductions in table 8.

In summary, net volumes on sample trees are calculated by use of the indicator-length deduction factors; net tree volumes are totaled. The appropriate flat percentage factor for hidden defect is applied to the total net sample volume. This gives the net sound volume of the sample, minus deductions for sweep, breakage in logging, and missing parts of trees such as broken tops.

## CONCLUSIONS

Two methods for estimating defects in standing white firs are presented. Either system may be used separately to determine net volumes of sample trees from timber cruises; however, each method may be advantageously used in given situations. For instance, the indicator-length deduction factors may be used effectively by experienced cruisers in timber sale surveys which are usually local.

The indicator-defect percentage factors may be most effectively used to develop inventory data for relatively large areas--for southwestern Oregon or working circles in the Rogue River National Forest, for instance. Results from tests of the estimating equations indicate that they may also accurately predict defect volumes of small numbers of trees from local areas, although their effectiveness would probably increase with larger numbers of trees. Since it is only necessary to indicate the presence of various indicators they are less subjective than the indicator-length deduction factors where the cruiser must estimate which portions of trees are defective. Thus, the indicator-defect percentage method could be more accurately applied by inexperienced personnel who are often used to cruise timber (Bruce and Cowlin 1968).

The estimating equations also lend themselves well to computer programs now used by many forest management agencies to develop inventory data.

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KEYWORDS: Defect deduction (-merchantable volume, white fir, *Abies concolor*, Indian paint fungus, *Echinodontium tinctorium*, Oregon (Rogue River National Forest).

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